APPENDIX 7

ARROW LNG PLANT

Groundwater Impact Assessment

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ARROW LNG PLANT - GROUNDWATER IMPACT ASSESSMENT

Gladstone, Queensland, Australia
Arrow CSG (Australia) Pty Ltd

Coffey Environments Australia Pty Ltd

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ABBREVIATIONS

AHD	Australian Height Datum
Arrow LNG Plant	Arrow Liquefied Natural Gas Plant
ANZECC	Australian and New Zealand Environment and Conservation Council
AS/NZS	Australian Standard/New Zealand Standard
DEM	Digital Elevation Model
DERM	Queensland Department of the Environment and Resource Management
DEWHA	Commonwealth Department of Environment, Water, Heritage and the Arts
DSEWPC	Commonwealth Department of Sustainability, Environment, Water, Population and Communities
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
EPP (Water) Policy	Environment Protection (Water) Policy
GIS	Geographic Information System
GLNG	Santos Gladstone Liquefied Natural Gas Project
GPC	Gladstone Ports Corporation
LNG	Liquefied Natural Gas
mAHD	Metres Australian Height Datum
MOF	Materials Offloading Facility
mbgl	metre below ground level
NHMRC	National Health and Medical Research Council
SWL	Static Water Level
TDS	Total Dissolved Solids

TWAF	Temporary Workers Accommodation Facility
UST	Underground Storage Tank
VOC	Volatile organic compound

GLOSSARY

Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.
Aquifer, confined	An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer.
Aquifer, semi-confined	An aquifer confined by a low-permeability layer that permits water to slowly flow through it. Also known as a leaky artesian or leaky confined aquifer.
Aquifer, unconfined	An aquifer in which there are no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Also known as a water table aquifer.
Aquifer, artesian	An artesian aquifer is a confined aquifer containing groundwater that will flow upward through a well, called an artesian well, without the need for pumping. Water may even reach the ground surface if the natural pressure is high enough, in which case the well is called a flowing artesian well.
Hydrogeological unit	A hydrogeological unit is a body of rock or sediment that has hydrogeological characteristics that make it distinct from surrounding bodies of rock or sediments. The boundaries are not necessary the same as the formation boundaries.
Chlorine method for estimation of recharge	Recharge rate is estimated using the chloride mass balance. R_e = P x (C_p/C_z) R_e = Recharge rate (mm/yr) C_z = mean chloride ion concentration in soil water (mg/L) C_p = Chloride ion concentration in rainfall (mg/L) P = Precipitation (mm/yr)
Coal seam gas	A form of natural gas extracted from coal beds; primarily methane.
Digital Elevation Model	A digital elevation model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques, but they may also be built from land surveying. DEMs

	are used often in geographic information systems, and are the most common basis for digitally-produced relief maps.
Environmental impact assessment	An environmental impact assessment is an assessment of the possible positive or negative impact that a proposed project may have on the environment, together consisting of the natural, social and economic aspects.
Environmental value	A measure of how we value the environment in which we live. A quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety.
Hydraulic conductivity	A coefficient of proportionality describing the rate at which water can move through a permeable medium. Also called a coefficient of permeability.
Impact assessment	An evaluation of the impact of a project on the physical, biological, cultural and social environments, as defined by the environmental values.
Magnitude of an impact	The scale or degree of an impact having in regard to its geographical extent, duration of effect and severity.
Liquefied natural gas	Natural gas that has been converted to liquid form for storage or transport. Liquefied natural gas takes up about 1/600th the volume of natural gas at a stove burner tip. It is odourless, colourless, non-corrosive, and non-toxic. When vaporized, it burns only in concentrations of 5 percent or 15 percent when mixed with air. The density of LNG is roughly 0.41 to 0.5 kg/L at -164°C
LNG train	A train is a term used to describe a processing plant that converts coal seam gas to LNG. A LNG plant can consist of one or more LNG trains.
Phreatophyte	A deep-rooted plant that can access water that it needs from the saturated zone (groundwater).
Potential impact	The impact on an environmental value from project activities (construction, operation and maintenance)
Potentiometric surface	An imaginary layer which defines the potentiometric levels for a confined aquifer. In an unconfined aquifer it is more commonly termed as the water table.
Reduced water levels	Water levels measured to a common datum (Australian Height Datum mAHD) are obtained by subtracting the measured depth of water below ground level from the ground surface elevation at a bore.
Residual impact	The enduring impact on an environmental value from project activities assuming the proper implementation of effective mitigation measures.

Saline-water encroachment	The movement, as a result of human activity, of saline groundwater into an aquifer formerly occupied by fresh water. Active saline-water encroachment proceeds owning to the lowering of the fresh-water potentiometric surface below sea level.
Sensitivity	An assessment of the susceptibility or vulnerability of an environmental value to change.
Significance of an impact	An assessment of the sensitivity of an environmental value and the magnitude of potential impacts on that value.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. Also called storage coefficient.
Sustainable yield for groundwater	The level of water extraction from a particular system that, if exceeded, would compromise key environmental assets, or ecosystem functions and the productive base of the resource.
Throughflow	The lateral movement of water in an unsaturated zone during and immediately after a precipitation event.
Transmissivity	The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid and the porous media, and the thickness of the porous media
Vadose zone	The zone between the land surface and the water table. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Also called the zone of aeration or the unsaturated zone.

EXECUTIVE SUMMARY

Coffey Environments Australia Pty Ltd was engaged by Arrow CSG (Australia) Pty Ltd to prepare the groundwater technical study for the Arrow LNG Plant project Environmental Impact Statement under the Queensland Government Terms of Reference.

The study area considered included the proposed LNG plant site located on Curtis Island, and mainland sites including the proposed temporary workers accommodation facilities, launch sites, and the feed gas pipeline and associated tunnel.

This report details the methodology of the study, provides an impact assessment, and identifies mitigation measures.

Assessment Methodology

The methodology included an assessment of baseline conditions, establishment of groundwater environmental values (including assessment of their sensitivity), and identification of potential impacts (including their magnitude) to the environmental values based on the project activities.

The significance of the potential impacts was assessed by considering both the sensitivity of the environmental values and the magnitude of the individual impacts to establish an unmitigated significance. Mitigation measures are proposed to reduce the impacts, and an assessment of mitigated significance was used to ensure that no adverse residual impacts remain.

An assessment of the cumulative impacts caused by the Arrow LNG Plant when considered in relation to other significant projects in the region was made.

Findings

The study found that shallow groundwater resources exist at all areas potentially impacted by the project footprint. The existing groundwater quality is generally poor and yields are low, and accordingly groundwater resources are not well developed in the study area.

The identified impacts and their assessed magnitude (unmitigated) are summarised in the following table.

LNG Plant	
Identified Impact	**Assessed Magnitude**
Reduced aquifer recharge	Very Low
Altered aquifer characteristics	Very Low
Degradation of groundwater quality through disturbance to acid sulfate soils	Moderate
Contamination of groundwater systems – spills and leaks	Moderate
Seepage of brine from Reverse osmosis (RO) plant	Moderate
Impacts on groundwater dependant ecosystems	Moderate

Excavation activities – dewatering	Low
Vertical migration of contaminants to deeper groundwater	Moderate
Plant Decommissioning	Moderate
Feed Gas Pipeline and Tunnel	
Identified Impact	**Assessed Magnitude**
Reduced aquifer recharge	Very Low
Altered aquifer characteristics	Very Low
Groundwater impacts from dewatering	High
Altered groundwater flow system due to tunnelling, causing saline intrusion	Moderate
Degradation of groundwater quality through disturbance to acid sulfate soils	High
Contamination of groundwater systems – spills and leaks	Moderate
Vertical migration of contaminants to deeper groundwater system	Moderate
Temporary Worker Accommodation Facilities and Launch Site 1	
Identified Impact	**Assessed Magnitude**
Reduced aquifer recharge	Very Low
Altered aquifer characteristics	Very Low
Degradation of shallow groundwater quality from leaks and spills of sanitation systems	Moderate
Contamination of groundwater systems – spills and leaks	Moderate
Degradation of groundwater quality through disturbance to acid sulfate soils	Moderate
Impact to groundwater dependant ecosystems	Moderate
Vertical migration of contaminants to deeper groundwater system	Moderate

The indicated impacts to groundwater environmental values range in magnitude from very low to high and the mitigation methods proposed should adequately deal with any impacts that are likely to arise (impacts associated with acid sulfate soils are identified but dealt with and mitigated separately in a specific technical study (Coffey Geotechnics, 2011b)).

After application of the mitigation measures, each of the residual impacts is assessed for significance. The residual impact significance for the mainland sites all ranged from very low to low indicating that the project development is unlikely to impact the mainland groundwater environment adversely when operated in accordance with the design and mitigation measures proposed.

The mitigated residual impact significance for the LNG plant site on Curtis Island ranged from low to moderate indicating that the project development is unlikely to impact the Island groundwater environment adversely when operated in accordance with the design and mitigation measures proposed.

For cumulative groundwater impacts to arise from the development and operation of these projects, such impacts must necessarily have a sufficient spatial extent to result in an overlap of impacted areas. However because the mitigated impacts identified are 1) very low to moderate and 2) of limited areal extent, then it is concluded that the residual cumulative impacts must also be no greater than as individually assessed.

Conclusions

It is concluded that adverse residual impacts are not indicated to occur to groundwater environmental values in the Arrow LNG Plant area of disturbance, and that the Arrow LNG Plant construction and operation will not contribute to the cumulative residual impacts of the other relevant major projects identified.

Adherence to the mitigation measures identified for the Arrow LNG Plant will satisfactorily mitigate the potential for cumulative impacts to occur.

Recommendations

An inspection and groundwater monitoring program has been described to include baseline monitoring and sampling, and ongoing monitoring following plant commissioning.

1 INTRODUCTION AND PROJECT DESCRIPTION

1.1 Introduction

Coffey Environments Australia Pty Ltd (Coffey Environments) has been appointed by Arrow CSG (Australia) Pty Ltd (Arrow Energy) to prepare the Environmental Impact Statement (EIS) for the proposed Arrow LNG Plant. This groundwater impact assessment report was prepared to meet the Shell Australia LNG Project Terms of Reference for an EIS (Queensland Government, 2010a). The Shell Australia LNG Project has since been renamed as the Arrow LNG Plant. This report describes the groundwater baseline conditions in the Arrow LNG Plant study area and assesses potential impacts to the groundwater systems. Mitigation measures are identified and residual and cumulative impacts of the project on groundwater resources are also assessed.

1.2 Proponent

Arrow CSG (Australia) Pty Ltd (Arrow Energy) is proposing to develop a LNG plant on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

The proponent is a subsidiary of Arrow Energy Holdings Pty Ltd which is wholly owned by a joint venture between subsidiaries of Royal Dutch Shell and PetroChina Company Limited.

1.3 Project Description

The Arrow LNG Plant study area is shown on Figure 1.1 in the regional context. Figure 1.2 shows the site locality in relation to adjacent project sites. Figure 1.3 shows the layout of the Arrow LNG Plant on Curtis Island.

1.3.1 Arrow LNG Plant

Arrow Energy proposes to construct the Arrow LNG Plant in the Curtis Island Industry Precinct at the south-western end of Curtis Island, approximately 6 km north of Gladstone and 85 km southeast of Rockhampton, off Queensland’s central coast. In 2008, approximately 10% of the southern part of the island was added to the Gladstone State Development Area to be administered by the Queensland Department of Local Government and Planning. Of that area, approximately 1,500 ha (25%) has been designated as the Curtis Island Industry Precinct and is set aside for LNG development. The balance of the Gladstone State Development Area on Curtis Island has been allocated to the Curtis Island Environmental Management Precinct, a flora and fauna conservation area.

The Arrow LNG Plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins via high-pressure gas pipelines to Gladstone, from which a feed gas pipeline will provide gas to the LNG Plant on Curtis Island. A tunnel is proposed for the feed gas pipeline crossing of Port Curtis.

The project is described below in terms of its key infrastructure components: the LNG Plant, the feed gas pipeline, and dredging operations.

Plant and Development Overview. The LNG Plant will have a base-case capacity of 16 Mtpa, with a total plant capacity of up to 18 Mtpa. The plant will consist of four LNG trains, each with a nominal capacity of 4 Mtpa. The project will be undertaken in two phases of two trains (nominally 8 Mtpa), with a financial investment decision undertaken for each phase.

Operations infrastructure associated with the LNG plant includes the LNG trains (where liquefaction occurs; see ‘Liquefaction Process’ below), LNG storage tanks, cryogenic pipelines, seawater inlet for desalination and stormwater outlet pipelines, water and wastewater treatment, a 110 m high flare stack, power generators, administrative buildings and workshops.

Construction infrastructure associated with the LNG plant includes construction camps, a concrete batching plant and laydown areas.

The plant will also require marine infrastructure for the transport of materials, personnel and product (LNG) during construction and operations.

Construction Schedule. The plant will be constructed in two phases. Phase 1 will involve the construction of LNG trains 1 and 2, two LNG storage tanks (each with a capacity of between 120,000 m^3 and 180,000 m^3), Curtis Island construction camp and, if additional capacity is required, a mainland workforce accommodation camp. Associated marine infrastructure will also be required as part of Phase 1. Phase 2 will involve the construction of LNG trains 3 and 4 and potentially a third LNG storage tank. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions and a financial investment decision at that time.

Construction Method. The LNG Plant will generally be constructed using a modular construction method, with preassembled modules being transported to Curtis Island from an offshore fabrication facility. There will also be a substantial ‘stick-built’ component of construction for associated infrastructure such as LNG storage tanks, buildings, underground cabling, piping and foundations. Where possible, aggregate for civil works will be sourced from suitable material excavated and crushed on site as part of the bulk earthworks. Aggregate will also be sourced from mainland quarries and transported from the mainland launch site to the plant site by roll-on, roll-off vessels. A concrete batching plant will be established on the plant site. Bulk cement requirements will be sourced outside of the batching plant and will be delivered to the site by roll on roll-off ferries or barges from the mainland launch site.

LNG Plant Power

Power for the LNG Plant and associated site utilities may be supplied from the electricity grid (mains power), gas turbine generators, or a combination of both, leading to four configuration options that will be assessed:

- Base case (mechanical drive): The mechanical drive configuration uses gas turbines to drive the LNG train refrigerant compressors, which is the traditional powering option for LNG facilities. This configuration would use coal seam gas and end flash gas (produced in the liquefaction process) to fuel the gas turbines that drive the LNG refrigerant compressors and the gas turbine generators that supply electricity to power the site utilities. Construction power for this option would be provided by diesel generators.
- Option 1 (mechanical/electrical – construction and site utilities only): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains. During construction, mains power would provide power to the site via a cable (30-MW capacity) from the mainland. The proposed capacity of the cable is equivalent to the output of one gas turbine generator. The mains power cable would be retained to power the site utilities during operations, resulting in one less gas turbine generator being required than the proposed base case.

- Option 2 (mechanical/electrical): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains and mains power to power site utilities. Under this option, construction power would be supplied by mains power or diesel generators.
- Option 3 (all electrical): Under this configuration mains power would be used to supply electricity for operation of the LNG train refrigerant compressors and the site utilities. A switchyard would be required. High-speed electric motors would be used to drive the LNG train refrigerant compressors. Construction power would be supplied by mains power or diesel generators.

Liquefaction Process

The coal seam gas enters the LNG Plant where it is metered and split into two pipe headers which feed the two LNG trains. With the expansion to four trains the gas will be split into four LNG trains.

For each LNG train, the coal seam gas is first treated in the acid gas removal unit where the carbon dioxide and any other acid gases are removed. The gas is then routed to the dehydration unit where any water is removed and then passed through a mercury guard bed to remove mercury. The coal seam gas is then ready for further cooling and liquefaction.

A propane, pre-cooled, mixed refrigerant process will be used by each LNG train to liquefy the predominantly methane coal seam gas. The liquefaction process begins with the propane cycle. The propane cycle involves three pressure stages of chilling to pre-cool the coal seam gas to -33°C and to compress and condense the mixed refrigerant, which is a mixture of nitrogen, methane, ethylene and propane. The condensed mixed refrigerant and pre-cooled coal seam gas are then separately routed to the main cryogenic heat exchanger, where the coal seam gas is further cooled and liquefied by the mixed refrigerant. Expansion of the mixed refrigerant gases within the heat exchanger removes heat from the coal seam gas. This process cools the coal seam gas further from -33°C to approximately -57°C. At this temperature the coal seam gas is liquefied (LNG) and becomes 1/600th of its original volume. The expanded mixed refrigerant is continually cycled to the propane precooler and reused.

LNG is then routed from the end flash gas system to a nitrogen stripper column which is used to separate nitrogen from the methane, reducing the nitrogen content of the LNG to less than 1 mole per cent (mol%). LNG separated in the nitrogen stripper column is pumped for storage on site in full containment storage tanks where it is maintained at a temperature of -163°C.

A small amount of off-gas is generated from the LNG during the process. This regasified coal seam gas is routed to an end flash gas compressor where it is prepared for use as fuel gas.

Finally, the LNG is transferred from the storage tanks onto LNG carriers via cryogenic pipelines and loading arms for transportation to export markets. The LNG will be re-gasified back into sales specification gas on shore at its destination location.

Workforce Accommodation

The LNG Plant (Phase 1), tunnel, feed gas pipeline, and dredging components of the project each have their own workforces with peaks occurring at different stages during construction. The following peak workforces are estimated for the project:

- LNG Plant Phase 1 peak workforce of 3,500, comprising 3,000 construction workers: 350 engineering, procurement and construction (EPC) management workers and 150 Arrow Energy employees.
- Tunnel peak workforce of up to 100.

- Feed gas pipeline (from the mainland to Curtis Island) peak workforce of up to 75.
- A dredging peak workforce of between 20 and 40.

Two workforce construction camp locations are proposed: the main construction camp at Boatshed Point on Curtis Island, and a possible mainland overflow construction camp, referred to as a temporary workers accommodation facility (TWAF). Two potential locations are currently being considered for the mainland TWAF; in the vicinity of Gladstone city on the former Gladstone Power Station ash pond No.7 (TWAF 7) or in the vicinity of Targinnie on a primarily cleared pastoral grazing lot (TWAF 8). Both potential TWAF sites include sufficient space to accommodate camp infrastructure and construction laydown areas. The TWAF and its associated construction laydown areas will be decommissioned on completion of the Phase 1 works.

Of the 3,000 construction workers for the LNG plant, it is estimated that between 5% and 20% will be from the local community (and thus will not require accommodation) and that the remaining fly-in, fly-out workers will be accommodated in construction camps. The 350 EPC management and 150 Arrow Energy employees are expected to relocate to Gladstone with the majority housed in company facilitated accommodation.

The tunnel workforce of 100 people and gas pipeline workforce of 75 people are anticipated to be accommodated in the mainland in company facilitated accommodation. The dredging workforce of 20 to 40 workers will be housed onboard the dredge vessel.

Up to 2,500 people will be housed at Boatshed Point construction camp. Its establishment will be preceded by a pioneer camp at the same locality which will evolve into the completed construction camp.

Marine Infrastructure

Marine facilities include the LNG jetty, materials offloading facility (MOF), personnel jetty and mainland launch site (Figure 1.2).

LNG Jetty. LNG will be transferred from the storage tanks on the site to the LNG jetty via above ground cryogenic pipelines. Loading arms on the LNG jetty will deliver the product to an LNG carrier. The LNG jetty will be located in North China Bay, adjacent to the northwest corner of Hamilton Point.

MOF. Delivery of materials to the site on Curtis Island during the construction and operations phases will be facilitated by a MOF where roll-on, roll-off or lift-on, lift-off vessels will dock to unload preassembled modules, equipment, supplies and construction aggregate. The MOF will be connected to the LNG Plant site via a heavy-haul road.

Boatshed Point (MOF 1) is the base-case MOF option and would be located at the southern tip of Boatshed Point. The haul road would be routed along the western coastline of Boatshed Point (abutting the construction camp to the east) and enters the LNG Plant site at the southern boundary. A quarantine area will be located south of the LNG Plant and will be accessed via the northern end of the haul road.

Two alternative options are being assessed, should the Boatshed Point option be determined to be not technically feasible:

- South Hamilton Point (MOF 2): This MOF option would be located at the southern tip of Hamilton Point. The haul road from this site would traverse the saddle between the hills of Hamilton Point to the southwest boundary of the LNG Plant site. The quarantine area for this option will be located southwest of the LNG Plant near the LNG storage tanks.

- North Hamilton Point (MOF 3): This option involves shared use of the MOF being constructed for the Santos Gladstone LNG Project (GLNG Project) on the northwest side of Hamilton Point (south of Arrow Energy's proposed LNG jetty). The GLNG Project is also constructing a passenger terminal at this site, but it will not be available to Arrow Energy contractors and staff. The quarantine area for this option would be located to the north of the MOF. The impacts of construction and operation of this MOF option and its associated haul road were assessed as part of the GLNG Project and will not be assessed in this EIS.

Personnel Jetty. During the peak of construction, base case of up to 1,100 people may require transport to Curtis Island from the mainland on a daily basis. A personnel jetty will be constructed at the southern tip of Boatshed Point to enable the transfer of workers from the mainland launch site to Curtis Island by high-speed vehicle catamarans (Fastcats) and vehicle or passenger ferries (ROPAX). This facility will be adjacent to the MOF constructed at Boatshed Point. The haul road will be used to transport workers to and from the personnel jetty to the construction camp and LNG Plant site. A secondary access for pedestrians will be provided between the personnel jetty and the construction camp.

Mainland Launch Site. Materials and workers will be transported to Curtis Island via the mainland launch site. The mainland launch site will contain both a passenger terminal and a roll on, roll-off facility. The passenger terminal will include a jetty and transit infrastructure, such as amenities, waiting areas and car parking. The barge or roll-on, roll-off facility will have a jetty, associated laydown areas, workshops and storage sheds.

The two location options for the mainland launch site are:

- Launch site 1: This site is located north of Gladstone city near the mouth of the Calliope River, adjacent to the existing RG Tanna coal export terminal.
- Launch site 4N: This site is located at the northern end of the proposed reclamation area for the Fishermans Landing Northern Expansion Project, which is part of the Port of Gladstone Western Basin Master Plan. The availability of this site will depend on how far progressed the Western Basin Dredging and Disposal Project is at the time of construction.

1.3.2 Feed Gas Pipeline

An approximately 8-km long feed gas pipeline will supply gas to the LNG Plant from its connection to the Arrow Surat Pipeline (formerly the Surat Gladstone Pipeline) on the mainland adjacent to Rio Tinto's Yarwun alumina refinery. The feed gas pipeline will be constructed in three sections:

- A short length of feed gas pipeline will run from the proposed Arrow Surat Pipeline to the tunnel launch shaft, which will be located on a mudflat south of Fishermans Landing, just south of Boat Creek. This section of pipeline will be constructed using conventional open-cut trenching methods within a 40 m wide construction right of way.
- The next section of the feed gas pipeline will traverse Port Curtis harbour in a tunnel to be bored under the harbour from the mainland tunnel launch shaft to a receival shaft on Hamilton Point. The tunnel under Port Curtis will have an excavated diameter of up to approximately 6 m and will be constructed by a tunnel boring machine that will begin work at the mainland launch shaft. Tunnel spoil material will be processed through a de-sanding plant to remove the bentonite and water and

will comprise mainly a finely graded fill material, which will be deposited in a spoil placement area established within bund walls constructed adjacent to the launch shaft. Based on the excavated diameter, approximately 223,000 m^3 of spoil will be treated as required for acid sulfate soil and disposed of at this location.

- From the tunnel receival shaft on Hamilton Point, the remaining section of the feed gas pipeline will run underground to the LNG Plant, parallel to the above ground cryogenic pipelines. This section will be constructed using conventional open-cut trenching methods within a 30 m wide construction right of way.

Should one of the electrical plant power options be chosen, it is intended that a power connection will be provided by a third party to the tunnel launch shaft, whereby Arrow Energy would construct a power cable within the tunnel to the LNG Plant.

Other infrastructure, such as communication cables, water and wastewater pipelines, may also be accommodated within the tunnel.

The tunnel will be designed and constructed for dry operations (‘tanked’ tunnel design). This is required because the services contained within the tunnel (feed gas pipeline, communications and potentially power cables) will require dry operating conditions.

The tunnel will have a 1:1000 slope (higher end at Curtis Island) with a sump at the tunnel entry on the mainland to collect any leakage water should this eventuate. Tunnel design has not been completed yet, however it is intended that any water collected in the sump will be pumped to the surface and discharged in line with the applicable legislative requirements, including any treatment that might be required.

1.3.3 Dredging Operations

Dredging required for LNG shipping access and swing basins has been assessed under the Gladstone Ports Corporation’s Port of Gladstone Western Basin Dredging and Disposal Project. Additional dredging within the marine environment of Port Curtis may be required to accommodate the construction and operation of the marine facilities. Up to five sites may require dredging:

- Dredge site 1 (dredge footprint for launch site 1): The dredging of this site would facilitate the construction and operation of launch site 1. This dredge site is located in the Calliope River and extends from the intertidal area abutting launch site 1, past Mud Island to the main shipping channel. The worst-case dredge volume estimated at this site is approximately 900,000 m^3.
- Dredge site 2 (dredge footprint for launch site 4N): The dredging of this site would facilitate the construction and operation of launch site 4N. This dredge site would abut launch site 4N and extend east from the launch site to the shipping channel. The worst-case dredge volume identified at this site is approximately 2,500 m^3.
- Dredge site 3 (dredge footprint for Boatshed Point MOF 1): The dredging of this site would facilitate the construction and operation of the personnel jetty and MOF at Boatshed Point. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.
- Dredge site 4 (dredge footprint for Hamilton Point South MOF 2): The dredging of this site would facilitate the construction and operation of the MOF at Hamilton Point South. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.

- Dredge site 5 (dredge footprint for LNG jetty): The dredging of this site will facilitate the construction of the LNG jetty at Hamilton Point. This dredge site extends from the berth pocket to be dredged as part of the Western Basin Strategic Dredging and Disposal Project to the shoreline and is required to enable a work barge to assist with construction of the jetty. The worst-case dredge volume identified is approximately 120,000 m^3.

The spoil generated by dredging activities will be placed and treated for acid sulfate soils (as required) in the Port of Gladstone Western Basin Dredging and Disposal Project reclamation area.

1.3.4 Project Details Relevant to the Assessment

Table 1.1 provides information about the project that is relevant to the groundwater impact assessment.

Table 1.1: Groundwater related information from the project description

Project component	Project details
Water supply on Curtis Island **Potable and non-potable water supply for LNG Plant**	No groundwater pumping or extraction will be required for the purposes of providing water supply. During construction of the pioneer camp: Potable and non-portable water will need to be imported. During other construction and operation: Potable and non-potable water supply will be obtained from the sea and desalinated. Desalination of seawater by reverse osmosis plants. Brine from reverse osmosis plant to be discharged to the harbour. Potable water, safety showers, eye baths, canteen, etc. Desalination of seawater and further treatment (remineralisation treatment and disinfection using chlorine, sodium hypochlorite or UV treatment) to meet the standards for drinking water quality.
Water supply for mainland activities	No groundwater pumping or extraction will be required for the purposes of providing water supply. Water will be from the town water supply or will be transported to site via water trucks.
Offsite stormwater	Stormwater originating upstream of the LNG Plant will be diverted around the site via a creek diversion and will be discharged to sea. Stormwater is considered separately in the technical study report 'Arrow LNG Plant Stormwater Quality Impact Assessment' (Alluvium, 2011a).
LNG Plant runoff from developed areas	Runoff from the developed areas on the LNG Plant site will be directed towards a controlled discharge facility which will collect the first 30 minutes of surface water run-off for possible treatment. Excess water beyond 30 minutes will be discharged to sea. Appropriate sedimentation controls are to be applied.
Tunnel spoil	The tunnel under Port Curtis will have an excavated diameter of up to about 5.65 m and will be constructed via a tunnel boring machine. Tunnel spoil materials will be processed to remove the bentonite and water and will be deposited in a spoil replacement area established within bund walls constructed adjacent to the launch shaft. The tunnel spoil disposal area is currently planned to be on the mudflat adjacent to the entrance to the tunnel. The tunnel launch shaft is planned to be at a depth between 12 m and 40 m. The tail-water will be put through an appropriate treatment plant and discharged to the

Project component	Project details
	intertidal area adjacent to the launch shaft through appropriate designed structures that reduces the potential for channelisation of the mudflat.
Tunnel Dewatering	The tunnel will be designed and constructed for dry operations ('tanked' tunnel design). Because the tunnel will be tanked there will be no groundwater drawdown associated with the tunnel once commissioned.
Feed gas pipeline	The feed gas pipeline from the proposed Arrow Surat Pipeline to the tunnel launch shaft will be constructed using conventional open-cut trenching method within a 40 m wide construction right of way. The feed gas pipeline from the tunnel received shaft on Hamilton Point to the LNG plant will be constructed using the conventional open-cut trenching methods within a 30 m wide construction right of way. It is planned that the trench will be 2 m deep and 1.2 m wide.
TWAF 7 and TWAF 8 sewage and potable water	Piped systems (connecting to the public services) for sewage and potable water will be available onsite. Alternatively, potable water will be trucked in and sewage collected and trucked offsite. There will be no treatment or discharge of sewage or wastewater on site.
Hamilton MOF, Boatshed Point MOF & haul road, cryogenic LNG run down pipelines, and LNG Jetty	These facilities and infrastructure will be partly built over the mud flats
Civil construction phase	Short duration dewatering may be required during excavations of foundations during the civil construction phase of the project.

1.4 Groundwater Study – Purpose and Objectives

The purpose of the study is to fulfil the groundwater related requirements of the Final Terms of Reference for the Shell Australia LNG Project (now Arrow LNG Plant) EIS, as issued by the Coordinator-General, January 2010 (Queensland Government, 2010a).

The key objectives of this groundwater study are to:

- Address groundwater relevant issues raised by the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) (formerly the Commonwealth Department of Environment, Water, Heritage and the Arts) in their decision notice when they advised that the project was a controlled action under the Environment Protection and Biodiversity Conservation (EPBC) Act;
- Discuss the legislative context of the project in terms of groundwater hydrology;
- Describe the existing environment for groundwater resources that may be affected by the project;
- Assess potential impacts of the project on groundwater resource environmental values;
- Define and describe objectives and practical measures for protecting or enhancing groundwater resource environmental values;

- Specify management strategies and monitoring programs for protecting groundwater quality during the construction, operation and decommissioning of the project;
- Present the findings of the study in a report to be appended to the Arrow LNG Plant EIS.

2 LEGISLATIVE CONTEXT

The Terms of Reference (Coordinator-General, 2010a) requires a description of the existing environmental values of the groundwater potentially affected by the proposed developments and operations.

The groundwater impact assessment also includes the review of the key relevant legislation, policies and guidelines as listed below (and summarised in Table 2.1):

- Water Act 2000 (Queensland Government, 2010).
- Environmental Protection Act 1994;
- Environmental Protection (Water) Policy 2009 (Queensland Government, 2009b);
- Petroleum and Gas (Production and Safety) Act 2004;
- State Planning Policy 2/02 Guidelines – Planning and Managing Development involving Acid Sulfate Soils, 2002, Queensland (Queensland Government, 2002);
- Australian and New Zealand Environment Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ, 2000), Guidelines for Fresh and Marine Water Quality;
- National Health and Medical Research Council (NHMRC) and Natural Resource Management Ministerial Council, 2004. Drinking Water Guidelines;

The Terms of Reference also requires a description of the existing environmental values of groundwater in the context of environmental values identified in the Environment Protection (Water) Policy (EPP (Water) Policy) (Queensland Government, 2009c) and an evaluation of the quality, quantity, and significance of artesian and non-artesian groundwater resources in the study area.

As described in the EPP (Water) Policy, the environmental values to be enhanced or protected include the following:

- Biological integrity of an unmodified, highly valued or modified aquatic ecosystem;
- Suitability for primary, secondary, and visual recreational use;
- Suitability for minimal treatment before supply of drinking water;
- Suitability for agriculture use;
- Suitability for aquaculture use;
- Suitability for producing aquatic food for human consumption;
- Suitability for industrial use; and
- Cultural and spiritual values of water.

Table 2.1: Review of relevant policies, guidelines and legislation

Policy or legislation	Description	Relevance to Arrow LNG Plant – Groundwater Impact Assessment
Water Act 2000 – State water resource and resource operation plans	The purpose of the Act is to provide for the sustainable management of water and other resources, a regulatory framework for providing water and sewerage services and the establishment and operation of water authorities. Water resource plans have been developed to define the availability and allocation of water and to ensure the sustainable management of water in Queensland. The objectives of the water resource plans are to balance the needs of humans and the environment in a sustainable manner.	Curtis Island is not within the area covered by a water resource plan. The study area on the mainland falls within the bounds of the water resource planning catchments and may be influenced by the following water resource plans: The Calliope River Basin Water Resource Plan 2006.
Environmental Protection Act 1994	The objective of the Environmental Protection Act is to protect the Queensland environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (Queensland Government, 1994). Subordinate to this act is the Environmental Protection Regulation 2008, which provides for the effective administration and enforcement of the objectives and provisions of the Environment Protection Act.	All persons must not carry out any activity that causes, or is likely to cause, environmental harm unless the person takes all reasonable and practical measures to prevent or minimise the harm (Section 319 of the Act). This general duty to the environment requires the implementation of pro-active measures to prevent environmental degradation and act in accordance with the precautionary principle. This requirement is underpinned by the impact assessment and mitigation process in this study.
Environmental Protection (Water) Policy (2009)	The purpose of the Environmental Protection (Water) Policy is to achieve the objectives of the Environmental Protection Act in relation to Queensland waters.	The environmental values are to be enhanced or protected (Section 6 of the Act). The relevant environmental values vary depending on the ecological value of the water, level of disturbance and intended use of the water. The management controls/mitigation measures in this study were prepared to meet the requirements of this policy.
Petroleum and Gas (Production and Safety) Act 2004	The purpose of this Act is to facilitate and regulate the carrying out of responsible petroleum activities and the development of a safe, efficient and	The petroleum tenure holder may take or interfere with groundwater taken during the course of an activity authorised under the petroleum tenure.

Policy or legislation	Description	Relevance to Arrow LNG Plant – Groundwater Impact Assessment
	viable petroleum and fuel gas industry. The distillation, production, processing, refining, storage and transport of fuel gas are included in "petroleum activities" covered by the Act.	The Act indicates that if the petroleum activity unduly affects an existing water bore, the tenure holder must implement restorative measures to ensure a suitable supply of water to the owner of the bore, or compensate the owner for being unduly affected. The mitigation measures in this study were prepared to meet the requirements of this Act.
State Planning Policy 2/02, Queensland	The purpose of this policy is to avoid potential adverse effects on natural and built environment and human health as the results of the development involving acid sulfate soils in low-lying coastal areas.	The release of acid and associated metal contaminants into the environment is avoided by treating, and if required, undertaking ongoing management of any disturbed acid sulfate soils and drainage waters. The monitoring program presented in this report was prepared to address this policy requirement.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000)	The ANZECC 2000 Guidelines have been prepared as part of Australia's National Water Quality Management Strategy. This strategy aims to achieve the sustainable use of Australia's water resources by protecting and enhancing their quality while maintaining economic and social development.	The ANZECC 2000 Guidelines provide guideline values or descriptive statements for different indicators to protect aquatic ecosystems and human uses of waters (e.g. primary recreation, human drinking water, agriculture, stock watering). The groundwater quality data of the study area was compared to the guidelines to identify the existing environmental value.
National Health and Medical Research Council Australian Drinking Water Guidelines (NHMRC, 2004)	The 2004 Australian Drinking Water Guidelines have been developed by the National Health and Medical Research Council in collaboration with the Natural Resource Management Ministerial Council. The Australian Drinking Water Guidelines incorporates the Framework for the Management of Drinking Water Quality and provides the Australian community and the water supply industry with guidance on what constitutes good quality drinking water.	The groundwater quality data for the study area was compared to the Australian Drinking Water Guidelines to help identify the existing environmental values of groundwater.

3 STUDY METHOD

The groundwater study method includes establishing baseline data and information, identifies potential impacts based on the proposed activities, assesses the significance of impacts on environmental values related to groundwater resources, and proposes mitigation measures.

The study adopts an approach which uses the significance of impacts to identify mitigation methods. Management measures are recommended to mitigate and/or reduce the potential impacts based on the initial groundwater impact assessment.

The groundwater study includes two main components:

- Establish the existing groundwater environmental (baseline) information; and
- Assess groundwater impacts and propose mitigation recommendations.

The specific tasks associated with these two components are detailed below.

3.1 Establish Groundwater Existing Environment (Baseline) Information

This phase of the work included the following scope:

- Collate and sight available documentation of groundwater related studies and information/data;
- Review of the relevant guidelines, policies and legislations;
- Search the Queensland Department of the Environment and Resource Management (DERM) groundwater database for existing bore data;
- Search the DERM Water Management System (WMS) database for groundwater user entitlement data;
- Identify registered groundwater stakeholders within 2 km of the study area;
- Sight reports of technical studies in relation to climatic data, geology, acid sulfate soils, surface water, fresh water aquatic ecology carried out by other consultant groups as parts of the project;
- Compile well and aquifer information including well depth, aquifer formation, bore yield, static water levels (SWLs) and groundwater quality;
- Compile available geological, hydrogeological data/information for the study area;
- Review the provided geospatial data and develop the hydrogeological baseline map using Geographic Information Systems (GIS);
- Identify and assess aquifers within the study area; and
- Characterise the groundwater regimes based on the available data.

3.2 Assess Groundwater Impacts and Identify Mitigation

This phase of the work included the following scope:

- Identify the baseline groundwater conditions of the study area and its environs based on the outcome of the desktop study described above.
- Identify the existing environmental values of groundwater resources and their sensitivity.
- Assess potential impacts associated with the project and estimate the magnitude of those impacts.
- Assess the significance of the identified impacts (pre-mitigated impacts).
- Identify appropriate control and mitigation measures.
- Assess the significance of residual groundwater impacts taking into account mitigation measures.
- Qualitatively assess cumulative impacts using publicly available environmental impact assessment reports of the projects relevant to the Arrow LNG Plant. The list of projects considered in the cumulative impact assessment is shown in Section 9.

3.3 Impact Assessment Methodology

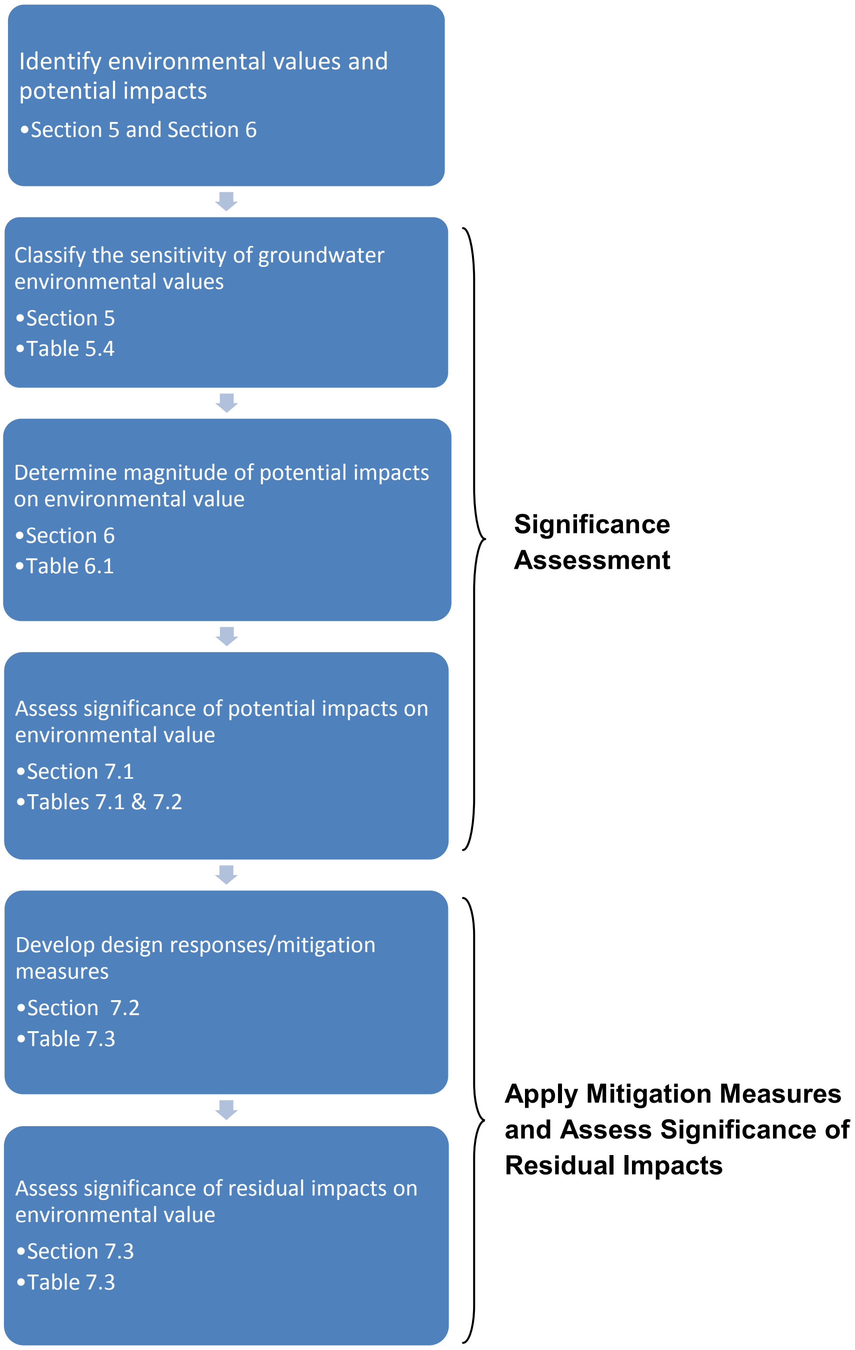
This study has used the significance approach to assess project impacts on groundwater. This approach considers existing environmental values and the sensitivity of these values to change. Impacts which may affect groundwater environmental values are identified and assessed in terms of potential magnitude. The significance of impacts on an environmental value is determined by the sensitivity of the value itself and the magnitude of changes it experiences.

This approach assumes the identified impacts will occur, and focuses attention on the mitigation and management of potential impacts through the identification and development of effective design responses and environmental controls. This is a conservative method that enables a more comprehensive understanding and assessment of the likely impacts of the project.

Application of appropriate management and mitigation measures will reduce the potential for adverse ‘residual impacts’ in the study area.

Chart 3.1 provides a flow chart for the overall impact assessment process (with cross-references to relevant tables and sections of this report associated with the method) and identifies those steps that comprise the significance assessment.

Chart 3.1: Impact and significance assessment - process flow and cross reference



4 EXISTING ENVIRONMENT

This section describes relevant aspects of the existing physical environment in the study area including climate, topography, geology, and hydrogeology. In addition, the environmental values for groundwater in the study area are characterised.

4.1 Climate Data

Based on the Köppen-Geiger climate classification the region is classified in the category Cfa (humid subtropical) typical of a climate zone characterised by hot, humid summers and cool winters.

Summer weather in the region is mainly influenced by location and the southeast trade wind belt, and is too far south to experience a regular north-west monsoonal influence (PaeHolmes, 2011). Storms are frequent in summer (relative to other seasons) due to the unstable atmospheric conditions that occur (PaeHolmes, 2011).

Climate data was obtained from the Australia Bureau of Meteorology (BOM, 2011). The climate of the study area experiences warm and wet summer months and drier winter months. Summer and spring are wet seasons (December to March) with more rainfall events occurring between October and March.

4.1.1 Rainfall

The average annual rainfall recorded at the Gladstone Radar weather station (station 039123) from 1957 to 2011 is 883.8 mm, and the average annual rainfall recorded at the Gladstone Airport weather station (station 039326) from 1994 to 2011 is 809.4 mm (Bureau of Meteorology, 2011).

The average annual rainfall recorded at the Gladstone Post Office weather station (station 039041) from 1872 to 1958 is 1020.8mm (Bureau of Meteorology, 2011).

Based on Gladstone Radar records, evaporation peaks in January at approximately 190 mm a month and is lowest in June at approximately 90 mm a month (PaeHolmes, 2011). The average annual evaporation is approximately 1,720 mm.

4.1.2 Temperature

Based on Gladstone Airport data the mean monthly minimum temperature ranges between 21 and 23°C in the summer and between 12 and 14°C in the winter (PaeHolmes 2011). The mean maximum temperatures vary between 30 and 32°C in the hottest months and between 22 and 23°C during the coldest part of the year (PaeHolmes, 2011).

4.1.3 Climate Change

Climate trends based on observed data show that the average annual rainfall in the Central Queensland region (which includes Gladstone) for the decade to 2007 has fallen by approximately 14% in comparison with the previous 30 years (PaeHolmes, 2011). Average annual temperatures in Central Queensland are seen to have increased by 0.5 °C from 2000 to 2009, and in most years since the late 1970s, an increase in the number of days over 35 °C was identified (PaeHolmes, 2011).

4.2 Topography

The topography of the study area is described in detail in the Arrow LNG Plant Geology, Landform and Soils Impact Assessment for the project (Coffey Geotechnics, 2011a) and is summarised below.

The topography of the study area on Curtis Island can be characterised as undulating hilly terrain with distinctive belts of northwest and north-south trending ridges. The ridges slope towards the coastline along the west and south where there are the coastal supratidal mudflats and mangrove swamps. The ground elevation ranges from 3 mAHD at the southern boundary to a height of 48 mAHD at the ridge in the north-western portion of the site. The terrain slopes gently (up to 7^{o}) upwards towards the north away from the coastal plain. Along the flanks of the ridge the slopes steepen up to 20^{o}. The area is generally well grassed and covered with vegetation and trees.

Topography on the mainland is characterised by four different physiographic regions:

- Steep, largely forested uplands (largely outside the study area).
- Coastal plains mainly comprising marine sediment mudflats with mangroves found along the coastal margins. Further inland, plains comprising alluvial and colluvial sediments rise gently towards the foothills and upland areas.
- The Gladstone built up region located to the southeast of the study area, comprising an altered and partly reclaimed landscape.

4.3 Geology

The geology of the study area is described in detail in the Arrow LNG Plant Geology, Landform and Soils Impact Assessment for the project (Coffey Geotechnics, 2011a) and is summarised below.

Mapped geology is covered on the Rockhampton 1:250,000 geological map (Geological Survey of Queensland sheet FS 56-13) and the 1:100,000 “Gladstone Special” geological map (Geological Survey sheet 9150 & Part 9151, March 2006). Figure 4.1a shows the geology of the study area, while Figure 4.1b presents the related hydrogeology (discussed further in Section 4.5).

The site of the LNG plant on Curtis Island is underlain mainly by the late Devonian to Early Carboniferous Wandilla Formation, part of the Palaeozoic Curtis Island Group. This formation is comprised of a sedimentary sequence including weakly metamorphosed mudstone, lithic sandstone, quartz greywacke, and siltstone. The subsoil stratification along the hilly undulating terrain generally comprises of residual/colluvial overburden underlain by weathered rocks. Along the low-lying terrain the regolith consists of alluvial overburden (gravels, sands, silts and clays) underlain by residual soils, in turn underlain by weathered rock. Alluvium is indicated in dissected gullies where fluvial processes have eroded into the bedrock. To the west of the LNG plant site, the Wandilla Formation is down-faulted and overlain by Tertiary and Quaternary alluvium and colluvium that extends to the foothills of the mainland.

Geotechnical borelogs from the LNG plant site that detail specific sub-surface lithology are provided in Appendix A. These logs report a range of lithology including silt and clay with varying amounts of gravel and sand, as well as interbedded siltstone and sandstone.

The mainland equivalent of the Wandilla Formation is comprised of the Doonside Formation. These rocks are separated from the Wandilla Formation by a north-west trending fault sub-parallel to the Yarrol Fault (itself located further west - Figure 4.1a). However the lithology is equivalent and references to Wandilla Formation may be generically used in this report as applicable to the Doonside Formation.

Portions of the far west of the study area, including some of the foothills, are intruded by or adjacent to the Triassic Targinie Granite and the older Devonian/Carboniferous Balnagowan Volcanics.

A simplified summary of the geological formations of relevance to a groundwater investigation are:

- Coastal/estuarine sediments including mudflats (Quaternary age);
- Alluvium and colluvium (Quaternary and Tertiary age);
- Sedimentary (including partly metamorphosed) bedrock (Palaeozoic age - variously weathered); and
- Igneous bedrock (Mesozoic granite, Palaeozoic volcanics).

4.3.1 Acid Sulfate Soils

Acid sulfate soils may occur in low lying areas of the coastal floodplains, rivers and creeks (below 5 m AHD) consisting of Holocene marine/estuarine mud. These soils could generate acid from the oxidation of iron sulphide minerals. Acid sulfate soils (ASS) in the study area have been assessed in the Acid Sulfate Soils technical study prepared for the project (Coffey Geotechnics, 2011b).

4.4 Groundwater Resources

A review of the existing groundwater resources in the study area was undertaken. This included a search of DERM registered groundwater bores (Appendix B). In addition, available information was reviewed and summarised from previous investigations, including unregistered geotechnical and groundwater bores.

To enable capture of a wider and more representative range of data for the groundwater resource assessment, an additional 2 km buffer was added to the study area when conducting bore searches.

4.4.1 Registered groundwater bores (DERM database)

Table 4.1 provides a summary of registered groundwater bores and screened lithology, within 2 km of the LNG study area boundary. Data was extracted from the DERM database in 2010 and is limited to registered bore users and may exclude other bore users within the region that are unregistered. Nevertheless, the data set is considered sufficient to provide a representative understanding of groundwater conditions for impact assessment purposes.

Available water quantity (as indicated by bore yields) and water quality (salinity) from DERM registered groundwater bores were used in preparing the salinity and yield information on Figures 4.2 and 4.3. This included data from bores beyond the 2 km study area buffer, to help understand regional water quality trends and how these may correlate with geology. This data is provided in Appendix B.

Groundwater bores were grouped into four classes based on the estimated salinity according to the classification of Groundwater Resources of Queensland Map (Queensland Water Resources Commission, 1987) as shown below.

- Table B1 lists DERM bores with TDS less than 500 mg/L.
- Table B2 lists DERM bores with TDS ranging from 500 mg/L to 1500 mg/L.
- Table B3 lists DERM bores with TDS ranging from 1500 mg/L to 5000 mg/L.

- Table B4 lists DERM bores with TDS greater than 5000 mg/L.

Based on the DERM data, the groundwater resources within the 2km of the Arrow LNG study area does not appear to be used for water supply. This is possibly a reflection of generally poor water quality, and low yields (hence limited sustainability of supply).

In addition, a search of the DERM Water Management System database for groundwater user entitlement data showed that there were no registered groundwater user entitlements allocated within the study area.

There are a total of 23 identified registered groundwater bores within the 2 km Arrow LNG study area boundary. Of these, there are three identified registered groundwater bores on the mainland located within the Arrow LNG study area (Figure 4.2). Two of the three registered groundwater bores (88464 and 111932) have low bore yields ranging from 0.65 L/s to 1.7 L/s and poor water quality (salinity ranging from 2,700 mg/L to 17,000 mg/L) (DERM 2010). The third registered groundwater bore (97440) is screened in fractured shale and has a bore yield of 3 L/s and a TDS of 585 mg/L (potentially potable quality). The three registered groundwater bores are highlighted in Table 4.1.

There are no identified registered groundwater bores on Curtis Island within the study area; however bore 91325 is a registered bore located about 200 m west of the study area boundary on the island (Figure 4.4). The salinity for this bore is 8,040 mg/L indicating brackish quality (Table 4.1).

Table 4.1: DERM registered groundwater bores within the Arrow LNG study area and 2 km buffer

Bore	Coordinates		Total Depth	Lithology	Aquifer Depth		SWL	Bore Yield	TDS	pH
	Easting	Northing	(m)		Top mbgl	Bottom mbgl	mbgl	L/s	mg/L	
84982	307311	7367306	27	granite	21	23	-	0.07	ND	ND
88338	312438	7363279	23.8	weathered granite	22	23.8	11.2	1	1,260	7.1
88456	306937	7367668	23.2	weathered granite	14	22.6	15	0.35	838	8.4
88459	306884	7367335	15.2	decomposed granite	ND	ND	5.9	ND	838	6
88464	311485	7366466	67	clay	62.5	65.6	ND	0.65	17,000	ND
91325	318603	7368993	27.3	mudstone	22.22	27.3	10.6	3	8,040	ND
91788	307328	7367509	19	decomposed granite	11	19	10	0.26	potable	ND
91789	307545	7365176	20	decomposed granite	10	20	6	2.6	737	ND
91795	307728	7364973	18	decomposed granite	9	18	4	5.7	636	ND
97440	311406	7366735	23	fresh, fractured shale	17	23	6.1 (2002)	3	603	ND
97960	308122	7365684	18	granite	13.7	ND	ND	1.26	1,206	ND
97989	307799	7365825	23	weathered granite	13	ND	11 (1997)	0.76	1,273	ND
111120	307428	7367308	36.5	granite	18.9	ND	15.24 (1993)	0.08	1,072	ND
111423	308071	7365576	25	decomposed granite	19.51	22.56	15.24 (1999)	0.45	737	ND
111797	321535	7361621	19	mudstone	17	19	9	0.75	1340	ND
111932	311485	7366466	36	shale	24	ND	9	1.7	2,700	ND
122097	322887	7361139	17	chert	6	17	4	1.51	838	ND
122932	314424	7361248	15	soft clay sandy	13	15	ND	0	ND	ND
122933	314110	7361429	14	medium-dense sandy clay	8.3	14	ND	0	ND	ND

Bore	Coordinates		Total Depth	Lithology	Aquifer Depth		SWL	Bore Yield	TDS	pH
	Easting	Northing	(m)		Top mbgl	Bottom mbgl	mbgl	L/s	mg/L	
122949	310780	7364287	24	weathered chert	18	24	6.7	2.5	838	ND
136123	321684	7360017	17.1	silty gravel	13	ND	11.1	1	potable	ND
136127	321794	7359636	19.7	coarse sand, gravel	12.9	ND	12.7	2.53	6000	
136231	312927	7362476	59	shale	49	ND	ND	0.03	ND	ND

Notes:

Data from DERM database (data extracted February 2010)

Highlighted bores located within Arrow LNG Plant study area

ND - no data/ no record

SWL - Standing water level

mbgl - metres below ground level

TDS - Total dissolved solids

Of the 23 registered groundwater bores within 2 km of the Arrow LNG study area, only two have complete groundwater quality records (88456 and 88459). Table 4.2 summarises the major ions in groundwater from these bores. Both are located near Fisherman's Landing (Figure 4.2).

Table 4.2: Groundwater chemistry data for DERM registered bores within the Arrow LNG Plant study area and 2 km buffer

Bore	Conductivity	pH	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	TDS
	µS/cm	Unit	mg/L								
88456	1,377	8.4	86.1	40.5	132	1	5.3	269.7	292	27	790
88459	1,486	6	46.4	34.7	193	9.6	0	19.1	302	233	956

Data from DERM database (data extracted February 2010)

Groundwater from these bores has a pH range from slightly acidic to slightly basic, and the TDS ranges from 790 to 956 mg/L indicating marginally potable water.

4.4.2 Unregistered groundwater bores

Unregistered groundwater bores have been identified within and adjacent to the study area, based on a survey of reports from relevant projects. Figure 4.3 shows the identified unregistered groundwater bores within and outside of the study area and Figure 4.4 shows unregistered groundwater bores on Curtis Island. Groundwater data from the projects reviewed as part of this assessment is discussed below.

Curtis Island Geotechnical Assessment prepared for Shell Global Solutions (Coffey Geotechnics 2009)

Eight geotechnical bores were drilled in 2009 during the geotechnical field investigations on Curtis Island for Shell Global Solutions. These geotechnical bores included BH1(09), BH2(09), BH4(09), BH5(09), BH7(09), BH8(09), BH9(09) and BH10(09) (Coffey Geotechnics 2009). These bores were dry during the drilling program and no piezometers were installed (Figures 4.5 and 4.6).

Arrow Energy LNG Project, Preliminary Geotechnical Investigation. Factual report – onshore LNG Facility, Curtis Island (Coffey Geotechnics, 2011c.)

A series of 26 geotechnical boreholes were drilled to depths varying between 8.1 m and 24.5 m below the existing surface level (mbgl) in 2010 during field investigations for Shell Global Solutions (Shell Australia LNG Project) (Coffey Geotechnics, 2011c).

Groundwater monitoring wells (piezometers) were installed at 5 locations across the site, those being BH02, BH12, BH16, BH17 and BH21 (Figures 4.5 and 4.6). All of these piezometers are located on Curtis Island within the study area, and Table 4.3 summarises groundwater hydraulic and quality data for them.

Five geotechnical boreholes were drilled on the mainland within the Arrow LNG study area as part of the same project. Of these, borehole BH35 was converted into a piezometer (Figure 4.5).

Table 4.3: Groundwater data from Arrow geotechnical bores on Curtis Island

Bore	Coordinates		Aquifer Interval	SWL	TSS	EC	pH	Al	B	Ca	Cl	Cu	Fe	K	Mg	Mn	Na	S	Zn
	Easting	Northing	m	mbgl	mg/L	mS/cm	unit	mg/L											
BH2	319275.1	7369846	1-4	Dry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH12	320238.8	9369118	0.3-3.3	0.03-0.45	12,000	136	3.8	19	2.9	838	130,000	0.3	0.4	1,840	4,440	31	1,480	2,380	1.9
BH16	319783.8	7368646	1-2.5	1.3-3.2	2,200	22	7.6	0.5	1	237	15,000	0.1	0.2	171	573	0.6	4,410	306	1.3
BH17	319438.5	7368434	0.5-3.5	0.01-1.03	2,200	158	6.8	0.8	3.2	684	150,000	0.1	0.2	3,070	4,400	1.8	1,990	2,840	1.2
BH21	317933.5	7368125	1.5-3	0.14-1.38	177	28	6.8	0.5	0.8	220	22,000	0.05	0.2	262	746	0.2	5,600	451	1.3

Notes:

Data from Coffey Geotechnics' drilling program on Curtis Island (2011)

SWL - Standing water level mbgl - metres below ground level

TSS - Total suspended solids

Gladstone LNG Environmental Impact Statement – Shallow Groundwater (URS 2009a)

A total of 14 groundwater monitoring bores were drilled and constructed in 2008 and 2009 on Curtis Island as part of the Gladstone LNG Project (URS 2009a). These included bores GW/BH1A, GW/BH1B, GW/BH2A, GW/BH2B, GW/BH3A, GW/BH3B, GW1, GW2S, GW2D, GW3, GW4S, GW4D, GW5 and GW6 (Figures 4.5 and 4.6). Table 4.4 details the bores.

Bores GW3, GW4S, GW5 and GW6 were installed in unconfined aquifers (alluvial/estuarine deposits, clay, sandy clay and bedrock). Bores GW1, GW2D and GW4D had screen intervals ranging from 16-27 mbgl in greywacke, and were installed in the confined bedrock aquifer.

Table 4.4: Groundwater data from geotechnical bores from the Gladstone LNG Project (URS 2009a)

Bore	Coordinates		Aquifer Type	Lithology	SWL	Hydraulic Conductivity	DO	EC	TDS	pH
	Easting	Easting			mbgl	m/day	mg/L	µS/cm	mg/L	unit
GW4S	318548	7368758	Unconfined	Clay and sandy Clay	4.4	0.004	0.1	9,060	5,436	5.71
GW5	319699	7368503	Unconfined	Clay and sandy clay	1.6	0.06	0.72	28,800	17,280	3.59
GW6	318790	7368334	Unconfined	Clay with trace of sand	4.6	0.003	0.4	24,000	14,400	6.66
GW1	317538	7369429	Confined	Fractured Greywacke	9.8	1.2	1.73	3,590	2,154	6.54
GW2S	318198	7369337	N/R	Silty, sandy clay and mudstone	Dry	-	-	-	-	-
GW2D	318196	7369336	Confined	Weathered greywacke	22.5	0.02	1.66	2,360	1,416	6.58
GW3	317412	7369164	Unconfined	Fractured greywacke	2.4	-	0.01	18,290	10,974	6.86
GW4D	318551	7368756	Confined	Sand & gravel greywacke	5.6	1	0.11	13,960	8,376	7.36
GW/BH1A*	314970	7372480	N/R	Clay	DRY	-	-	-	-	-
GW/BH2A*	315573	7372516	N/R	Clay	6.3	-	2.96	12,680	-	6.19
GW/BH3A*	315594	7370962	N/R	Mudstone/Siltstone	5	0.006	2.04	2,850	-	6.1
GW/BH1B*	314973	7372489	N/R	Clay argillite	11.21	0.06	2.3	40,300	-	5.35
GW/BH2B*	315578	7372513	N/R	Siltstone	6.4	0.03	2.5	18,290	-	5.99
GW/BH3B*	314970	7372480	N/R	Clay	5.25	0.04	0.92	21,470	-	5.85

Notes: *Data from URS Report (2009a)*
GW1 to GW6 - bores installed in May 2008 *Bores installed in August 2009
SWL - Standing water level mbgl - metres below ground level DO - Dissolved Oxygen EC - Electrical Conductivity N/R – Not reported

Gladstone Ports Corporation – Report for Western Basin Dredging and Disposal Project (GHD 2009)

A total of 15 groundwater monitoring bores were drilled and constructed on the mainland as part of the Gladstone Ports Corporation Western Basin Dredging and Disposal Project (GHD 2009). These included bores WB01-A, WB01-B, WB02-A, WB03-A, WB03-B, WB04-A, FL01-1A, FL01-1B, FL98-1A, FL98-1B, FL98-2A, FL98-2B, FL98-3, FL98-4 and CSGW-2 (Figure 4.7). Hydraulic conductivity values were estimated for six bores and details are included in Table 4.5.

Table 4.5: Groundwater data from Gladstone Ports Corporation Western Basin Dredging and Disposal Project (GHD 2009)

Bore	Coordinates		Elevation (TOC)	Bore Depth	Hydraulic Conductivity	Screen Interval	Lithology of screened formation
	Easting	Northing	mAHD	mbTOC	m/day	m AHD	
WB01-A	310693	7370071	3.31	20.79	0.003	-13.7 to -16.7	Silty clay/extremely weathered siltstone
WB01-B	310694	7370067	3.29	7.75	0.5	-0.7 to -3.7	Sandy clay
WB02-A	310175	7370112	7.07	20.82	0.00073	-9.9 to -12.9	Clay with trace sand
WB03-A	311319	7368957	4.54	19.75	0.04	-11.5 to -14.5	Clay
WB03-B	311323	7368959	4.41	6.20	0.034	1.9 to -1.1	Clay, lenses of sandy clay
WB04-A	310783	7368616	17.02	20.73	-	0.2 to 2.8	Sandy clay
FL01-1A	311773	7367698	13.17	17.44**	-	1.2 to -4.2*	Quaternary-aged colluvium*
FL01-1B	311771	7367697	13.18	4.88**	-	11.3 to 8.3*	Quaternary-aged colluvium*
FL98-1A	311900	7367343	14.79	14.54**	-	3 to 0	Quaternary-aged colluvium*
FL98-1B	311897	7367345	14.86	8.25**	-	12.8 to 9.5	Quaternary-aged colluvium*
FL98-2A	312139	7367618	5.93	13.50**	-	-3.0 to -9.5	Quaternary-aged colluvium*
FL98-2B	312142	7367615	6.09	4.15**	-	4.05 to 0.70	Quaternary-aged colluvium*
FL98-3	312116	7367000	9.19	10.3**	-	5.2 to 1.9	Quaternary-aged colluvium*
Fl98-4	311716	7367127	16.25	16.3**	-	11.7 to 5.4	Quaternary-aged colluvium*
CSGW-2	312913	7367456	3.81	4.5**	0.1	2.3 to -0.7*	Fill*

Notes:

Data from Gladstone Ports Corporation report (Western Basin Dredging and Disposal Project – Environmental Impact Statement, 2010; Tables 1 & 8-9, 42/15386/51971)

TOC - Top of casing SWL - Standing water level

*Assumed data

**Bore census (from Gladstone Ports Corporation, 2009, Table 1, report 42/15386/51/391007)

4.5 Hydrogeology

This section describes the characteristics of the study area hydrogeology (aquifer occurrence, recharge and discharge, hydraulic conductivity, groundwater levels and flow, and groundwater quality) based on the review of available data. Figure 4.1b presents the published hydrogeological mapping for the region.

4.5.1 Aquifer Occurrence and Morphology

Based on the available data from bore logs, geological mapping, and DERM groundwater data, groundwater occurs within the study area in a range of lithologies and conditions. The following aquifer morphologies are indicated:

- Unconfined aquifers (shallow aquifers within unconsolidated alluvial or estuarine deposits, colluvial deposits, and shallow fractured rock).
- Confined aquifers (weathered rock and fractured rock underlying low permeable layers; may also occur in lower strata of stratified alluvium).
- Semi-confined aquifers (fractured bedrock, zones of deeper weathering, transition zones between weathered and fresh bedrock, stratified alluvium). (For impact assessment purposes, semi-confined aquifers are considered a subset of confined aquifers, and treated as such).

Alluvial or estuarine formations commonly form shallow unconfined aquifers, and these are expected to occur in many parts of the study area in the vicinity of stream systems (typically alluvium, including gravel, sand silt and clay) and the coast (sand, silt, and clay). These are likely to occur where mapping indicates Quaternary alluvium (Figure 4.1a) and this includes those parts of the study area where unconsolidated sediment is mapped. However, unconfined aquifers may also occur within weathered or fractured bedrock, typically in higher topographic areas, distal from coasts or stream systems.

Aquifer thicknesses are indicated (based on the available bore data) to range from a few metres to several tens of metres in thickness. This feature of aquifers is topographically influenced and difficult to characterise in other than general terms.

Based on the existing mapped geology and hydrogeology, shallow Quaternary alluvial (unconfined) aquifers are likely to occur at:

- The Curtis Island LNG plant site (lower lying areas).
- Shoreline areas of the LNG plant marine site.
- TWAF 7.
- TWAF 8 (including Tertiary colluvium).
- Shoreline areas of the proposed launch sites.
- The proposed tunnel launch site and disposal areas.

Shallow unconfined bedrock aquifers (including fractured and weathered rock) may occur at:

- The Curtis Island LNG plant site (higher ground areas – within Wandilla Formation).
- TWAF 7 (within Wandilla Formation).
- TWAF 8 (within weathered granite).

Confined (or artesian) aquifers were encountered at some locations during the groundwater drilling programs within and adjacent to the study area (refer Section 4.4). It is feasible that confined aquifer systems containing groundwater under pressure may also occur in other locations. Based on geological indications this might be expected to comprise fractured Palaeozoic bedrock aquifers or Tertiary alluvial aquifers underlying more recent Quaternary cover. Potential locations for confined systems include the mainland foothills terrain within the study area where Quaternary sediment (alluvium and colluvium) overlies Triassic bedrock. This terrain is approximately coincident along the north-easterly trending fault through the mainland portion of the study area. However with the exception of TWAF 8, this alignment does not intersect planned development locations.

In the vicinity of TWAF 8 it is possible that fractured granite is obscured at depth beneath Quaternary alluvial cover, close to indicated low salinity groundwater resources (Figure 4.1a). It is feasible that a confined aquifer within the granite might occur at some depth within the TWAF 8 location, although without field drilling data this cannot be confirmed.

4.5.2 Groundwater Recharge and Discharge

Diffuse Recharge

Groundwater recharge to superficial aquifers commonly occurs through diffuse processes involving deep percolation of infiltrated rainwater through the sub-surface to the watertable. This net recharge represents that component of infiltrated surface water that is not lost to the atmosphere through evaporation and plant transpiration (evapotranspiration). In warm humid environments diffuse recharge rates can be moderate to high, leading to shallow watertables because potential evaporation is moderated by higher humidity, and doesn’t exceed rainfall significantly (compared with drier temperate or semi-arid climates). The study area receives regular rainfall with a bias towards higher rainfall occurring between October and March. As a result diffuse recharge may be higher during this period.

Diffuse recharge may also occur in upland areas where aquifer formations outcrop or have coarser, thinner and less mature cover sediments. This may include the higher relief areas located to the west and south-west of the study area, and also the upland terrain on Curtis Island to the north and north-west of the LNG plant site.

These upland recharge processes may be important sources of recharge for fractured bedrock aquifers (that exist under confined conditions in low lying areas) and local colluvial aquifers.

Estimates for groundwater recharge have previously been made for locations near the study area. In one case, the study for the Gladstone Ports Corporation Western Basin Dredging and Disposal Project (located near the Arrow LNG Plant study area on the mainland) estimated a long-term average (2000-2009) recharge value ranging from approximately 14 mm/year in upland tree covered areas to approximately 49 mm/year in lower lying grassland areas (Gladstone Ports Corporation, 2009).

In another case, for the Gladstone LNG project, aquifer recharge on Curtis Island was determined utilising the chloride method. Base on this method estimated average annual recharge rates for shallow aquifers were at 1 mm/year and for deep aquifers (>20 m) were estimated at 3 mm/year (URS 2009a).

The wide variation in results for these methods illustrates the difficulty that can be had in reliably quantifying these parameters for aquifers.

Much of the LNG plant area is significantly vegetated and evapotranspiration rates are assumed to be high compared to cleared areas. Clearing of land for development will reduce transpiration losses and could to result in an increase in net recharge, although is likely to be offset by a reduction in infiltration caused by development cover (from buildings, concrete, hardstand, etc).

Focussed Recharge

Higher rates of recharge can occur through focussed recharge processes that occur through concentration associated with depressions in surface topography such as streams, lakes, or wetlands.

Recharge can occur to unconfined aquifers in settings where streams have base levels above the watertable (‘losing’ streams). This is more likely to occur in upland stream settings where watertables can be deeper. In the study area the main coastal stream systems are likely to be receiving bodies (‘gaining’ streams), and this is supported by groundwater level data from bores in the study area.

In the study area, geomorphic features such as colluvial slopes may also cause localised concentrations of recharge due to higher vertical permeability within these formations and funnelling of runoff from the ranges through these features. No specific work to characterise these processes has been identified (and probably does not exist).

In general for the study area, diffuse recharge is considered to be the dominant recharge process for the aquifer systems present.

Groundwater Discharge

Based on topography and position in the landscape, groundwater in shallow alluvial aquifers would be expected to discharge at the coast and into streams and estuaries as baseflow (in particular Calliope River and Auckland Creek). Coastal groundwater discharge is likely to occur within inter-tidal zones, commonly comprising sands and mudflats. Deeper aquifers would be expected to discharge further into the marine environment, possibly beyond the littoral zone.

Due to capillary effects, discharge through evaporation is likely to occur from shallow aquifers where depth to groundwater is within 2 m of the surface in clayey or silty environments. This would include near shore areas and mudflats at low tide. Discharge through plant transpiration is likely to occur from shallow aquifers at greater depths (for example where depth to groundwater is within several metres or more of the surface) where deep rooted phreatophytes grow.

Groundwater discharge may also occur at springs, if they occur. Springs could occur in a range of geological and topographical settings. Within the study area this could include local flow system discharge at break of slope areas on the mainland. No springs have been identified in the study area.

4.5.3 Hydraulic Conductivity

Hydraulic conductivity is a measure of the permeability of rocks and sediments to groundwater movement. Few physical parameters in the natural environment show as much variation as this, and hydraulic conductivity can range by up to 12 orders of magnitude in naturally occurring geological formations. Within a given formation, the variability is often more constrained, and it is common for this parameter to range through two to three orders of magnitude even at site scale. Groundwater calculations and modelling based on this parameter must necessarily provide either a range of results, or be based on a bulk hydraulic conductivity value that is representative of the typical properties of the aquifer overall.

Within the study area groundwater occurs in both porous-media (for example material that contains primary porosity in the form of connected pore-spaces such as sediments, or rock that has weathered to a particle structure) and fractured rock geologies (where groundwater flow is mainly within secondary pore-space such as fractures and joints).

Groundwater flow in the bedrock within the study area is expected to be predominantly through a network of fractures or joints. The yields obtained from bores within the study area are low which corresponds to a relatively low intrinsic permeability and therefore limited groundwater movement through the water bearing formations. The Wandilla Formation bedrock has limited groundwater development potential due to the generally low primary porosity. Secondary processes (faulting and fracturing) may have created zones of increased permeability within this formation at some locations.

The reported hydraulic conductivity from bores tested within the study area is highly variable as expected, and was found to range from 0.0002 m/d to 1.2 m/d (Tables 4.5, 4.6). The highest hydraulic conductivity value observed was from fractured greywacke at bore GW1 (bedrock) on Curtis island, whilst the lowest observed was from bore GW/BH1A screened in clay (Figure 4.5).

Aquifer tests were conducted on Curtis Island for the Gladstone LNG project and gave the following results for hydraulic conductivity (Table 4.4):

- Alluvial/Estuarine Deposits (clay and sandy clay) – 0.003 m/d to 0.06 m/d.
- Bedrock (Wandilla Formation) – 0.006 m/d to 1.2 m/d.

Aquifer tests conducted at mainland boreholes west of Fisherman's Landing gave the following results for hydraulic conductivity (Table 4.5):

- Alluvial/Colluvial Deposits (clay, silty clay and sandy clay) – 0.00073 m/d to 0.05 m/d.
- Weathered Siltstone – 0.003 m/d.

Based on the data from both the abovementioned test sequences, the overall mean and median hydraulic conductivity for the alluvial/colluvial deposits are 0.09 m/d and 0.04 m/d respectively.

Based on the data from both the abovementioned test sequences, the overall mean and median hydraulic conductivity for the bedrock aquifer are 0.4 m/d and 0.5 m/d respectively.

These values are consistent with lithology in the study area, and suggest that the bedrock has generally higher permeability than the alluvium/colluvium.

4.5.4 Groundwater Levels and Flow

Available geological and hydrogeological information was compiled for the study area. The available data allowed for an initial assessment of the groundwater resource within the shallow (alluvial/colluvial/estuarine deposits) and deeper (bedrock) aquifer systems on the mainland and Curtis Island within the study area.

The DERM database provided limited groundwater level data from 23 registered groundwater bores on the mainland and Curtis Island within the vicinity of the Arrow LNG study area (Table 4.1). It is recognised that the DERM groundwater database contains data which has not been fully validated or verified and contains data that may vary over time (e.g. groundwater levels). However, the available data is considered sufficient to allow for an initial baseline level assessment of the groundwater systems within the study area.

Groundwater levels from unregistered bores were also sourced from the following reports:

- Gladstone Ports Corporation Western Basin Dredging and Disposal Project (GHD 2009).
- Gladstone LNG Environmental Impact Statement – Shallow Groundwater (URS 2009a).
- Arrow Energy LNG Project, Preliminary Geotechnical Investigation. Factual report – onshore LNG Facility, Curtis Island (Coffey Geotechnics, 2011c.).

This network of monitoring bores is considered to provide satisfactory spatial coverage within and surrounding the study area, and includes shallow and deeper groundwater aquifers. The Curtis Island and mainland groundwater conditions are considered separately below.

Curtis Island

The available groundwater level data, across a large area of undulating topography, was obtained from both alluvium and bedrock formations. Previous investigations carried out by URS (2009) for Gladstone LNG on Curtis Island (located west of the Arrow LNG study area) observed groundwater levels that ranged from 1.6 to 4.6 mbgl in the shallow alluvial/estuarine deposits. Groundwater levels measured in boreholes installed in the bedrock aquifer ranged from 2.4 to 22.5 mbgl (URS 2009a). These data do not allow for the accurate depiction of the groundwater flow patterns within the Arrow LNG study area. Both aquifers indicate poor relationships between elevation and groundwater levels; and this may indicate non-continuous confining layers across the area, leading to variable piezometeric levels within the monitoring bores, and difficulty in interpreting groundwater flow patterns on Curtis Island.

Groundwater levels ranged from 0.01 to 3.2 mbgl in piezometers BH12, BH16, BH17 and BH21 that were installed for Shell Global Solutions by Coffey Geotechnics in 2010 (Figure 4.4). These piezometers were installed in the shallow aquifer system on Curtis Island within the study area. Groundwater was not intersected in the deeper aquifer system during investigations at this time. The irregular groundwater elevations across Curtis Island does not allow for a dominant groundwater flow direction to be defined. Topographic considerations and the constant-head boundary at the coast, would suggest that groundwater flow will be from upland recharge areas towards the coast. Local hydrological boundaries such as streams and estuaries are also likely to receive groundwater discharge and locally influence groundwater flow direction.

Mainland

Groundwater levels measured in July and September 2009 along the coastal strip (WB01-A, WB01-B, WB03-A and WB03-B; Figure 4.7) in the northwest of the Arrow LNG Plant study area ranged from 0.7 to 2.8 mbgl. Groundwater levels further inland ranged from 4.5 to 7.4 mbgl (URS 2009a). The observed groundwater levels obtained from the DERM registered groundwater bores within the deeper aquifer system ranged from 0.6 to 28 mbgl. This large range is considered to result from wide variation in screened depths, and different topographic and stratigraphic locations.

Historical groundwater level data (2001-2009) from monitoring bores on the mainland within the Arrow LNG Plant study area indicate that typical seasonal fluctuations in groundwater levels of 0.4 to 1 m in the shallow groundwater system (GHD 2009). Seasonal fluctuations of greater than 1 m have also been recorded near coastal areas as a result of tidal movements. Tide information for Gladstone (BOM 2009) indicates that the tidal range for the Gladstone area is typically in the order of 1.5 to 4.5 m.

Groundwater elevations on the mainland are generally consistent with a groundwater flow direction from southwest to northeast (towards the coast).

Groundwater monitoring in bedrock (deeper) aquifers was not undertaken in the study area. Groundwater flow is expected to be influenced by the topographic gradient, with flow from southwest to northeast towards the coast.

4.5.5 Groundwater Quality

The classification of water based on total dissolved solids can be summarised as follows (Fetter, 2001).

Fresh:	TDS = 0 – 1,000 mg/L
Brackish:	TDS = 1,000 – 10,000 mg/L
Saline:	TDS = 10,000 – 100,000 mg/L
Brine:	TDS > 100,000 mg/L

This classification scheme has been adopted for descriptive purposes in this report.

Alluvial/Estuarine Sediments

The analysis of the major ion groundwater chemistry data from the Gladstone Ports Corporation Western Basin Dredging and Disposal Project (GHD 2009) showed that groundwater in the shallow alluvial/estuarine deposits on the mainland can be classified as sodium-chloride type water. The measured electrical conductivity (EC) values ranged from 6,900 to 61,900 μS/cm (GHD 2009) which indicate brackish to saline groundwater within the study area. pH was measured to be neutral to slightly acidic. The high EC indicates that the groundwater in the alluvial/estuarine material on the mainland within the study area is generally unsuitable for drinking, stock watering and irrigation.

Major ion groundwater chemistry from shallow piezometers installed for Arrow (Shell Global Solutions) showed that the groundwater on Curtis Island within the Arrow LNG study area is sodium-chloride type with groundwater EC ranging from 22,000 to 158,000 μS/cm (Coffey Geotechnics 2011c). This indicates a range from saline to brine (hypersaline).

Bedrock

A search of DERM registered groundwater bore database indicates that the majority of the registered groundwater bores within 2 km of the study area boundary (Figure 4.2 and Table 4.1) have TDS ranging between 500 and 5,000 mg/L, or fresh to brackish groundwater. One inconsistency is bore 88464 which has saline water with a measured TDS of ~17,000 mg/L.

The DERM registered groundwater bore 91325 on the Gladstone LNG site adjacent to the study area (Table 4.2) provides moderate yields (3.0 L/s) of brackish groundwater (TDS 8,040 mg/L) and is used for stock watering.

Analytical laboratory data for major cations and anions were available for only two DERM registered groundwater bores (88456 and 88459 – refer Table 4.2). These two bores are located west of Fisherman's Landing (Figure 4.2). The piper diagram on Figure 4.8 shows the hydrochemical characteristic of groundwater from these bores and was used to classify the hydrochemical water types present. The water chemistry is dominated by sodium cations and the water type is classified as sodium-chloride type.

Based on a review of the geological data and drilling results from the Gladstone LNG project on Curtis Island (located west of the Arrow LNG Plant study area), the EC and TDS measured in the monitoring bores indicate that the groundwater is brackish in the deeper boreholes (GW1, GW2D, and GW4D) and saline in the shallow bores (GW5, GW6, and GW3). These results suggest that there may be limited interaction between the shallow and deep aquifers.

The groundwater in both the shallow and deep bores has an acidic to neutral pH and is generally reducing, with the exception of GW5 which is oxidised (URS 2009a).

Groundwater Quality - General

The groundwater resources, as assessed from data for boreholes located in the vicinity of the study area, are limited and are of poor quality. The reported bore yields, static water levels and water quality were based on the available records at time of the study and may vary with time and spatially.

The DERM registered groundwater bore database indicates that the majority of the registered groundwater bores within the hydrogeological map domain (Figure 4.2) have salinity ranging between 500 and 5,000 mg/L (Table 4.2 and Appendix B). The hydrogeological map (Figures 4.2 and 4.3) shows the locations of groundwater bores that were classified based on groundwater quantity and quality.

The salinity data of 23 DERM registered bores within 2 km of the study area indicated groundwater quality ranging from fresh to brackish water types, except for the saline water (TDS = 17,000mg/L) at bore 88464 (Table 4.2).

Investigation Criteria

The ANZECC (2000) investigation levels adopted to provide a comparison of the groundwater analytical results were:

- The Trigger Levels for Freshwater Ecosystems – 95% protection level of species;
- The Trigger Levels for Marine Ecosystems – 95% protection level of species; and
- The Livestock Drinking Water Guidelines – Beef.

Table 4.6 summarises selected groundwater quality guideline values that are relevant to the study from ANZECC (2000) and the NHMRC (2004) guidelines.

Table 4.6: Groundwater quality guideline criteria

Parameter	Unit	NHMRC 2004 Drinking Water Guidelines (1)	ANZECC 2000 Freshwater Guidelines (2)	ANZECC 2000 Marine Water Guidelines (3)	ANZECC 2000 Irrigation Guidelines (LTV) (4)	ANZECC 2000 Livestock Drinking Water Guidelines (Beef) (5)
TDS (10)	mg/L	500 (8)	-	-	Crop & soil dependent	4000 (6) 5000 (7)
pH	unit	6.5 to 8.5	-	8.0 to 8.4	6.5 to 8.5	6.5 to 8.5
Sodium	mg/L	180 (8)	-	-	-	-
Chloride	mg/L	250 (8)	-	-	-	-
Sulfate	mg/L	500	-	-	-	2000 (9)

Nitrate	mg/L	50	0.7	0.005 (11)	-	1500 (9)
Iron	mg/L	0.3 (8)	-	-	0.2	-
Manganese	mg/L	0.5	1.9	-	0.2	-
Zinc	mg/L	3 (8)	0.008	0.015	2	20
Aluminium	mg/L	-	0.055	-	5	5
Boron	mg/L	0.004	0.37	-	0.5	5
Copper	mg/L	2	0.0014	0.0013	0.2	1

Notes:

(1) NHMRC 2004 National Health and Medical Research Council and Natural Resource Management Ministerial Council Australian Drinking Water Guidelines.
(2) ANZECC 2000 Australia and New Zealand Environment and Conservation Council Guidelines for Fresh and Marine Water Quality – Trigger Levels for Freshwater Ecosystems – 95% protection level of species.
(3) ANZECC 2000 Australia and New Zealand Environment and Conservation Council Guidelines for Fresh and Marine Water Quality – Trigger Levels for Marine Ecosystems – 95% protection level of species.
(4) ANZECC 2000 Australian and New Zealand Guidelines for Fresh and Marine Water Quality – Long-term Trigger Values (LTV) in Irrigation Water.
(5) ANZECC 2000 Australian and New Zealand Guidelines for Fresh and Marine Water Quality – Livestock Drinking Water Guidelines (Beef Cattle).
(6) Upper limit for no adverse affect to livestock.
(7) Lower limit at which point a loss of production and a decline in livestock condition and health would be expected.
(8) Aesthetic guideline value determined on the basis of taste.
(9) Toxicity threshold.
(10) TDS: Total Dissolved Solids.
(11) NOx

The groundwater results were evaluated against the ANZECC guidelines for livestock drinking water, and against the guidelines for freshwater and marine environments (relevant for consideration of the potential for discharge of groundwater into surface water bodies, groundwater dependant environments, and marine environments).

It is noted that the concentrations of some parameters in both the shallow and deeper groundwater systems exceeds the ANZECC guidelines for Freshwater and Marine Ecosystems. The groundwater, from both shallow (< 8 m) and some deep (> 20 m) bores, is recognised as not suitable for discharge into the fresh or marine water environments, nor for domestic use due to elevated dissolved metals.

GHD (2009) reported a range of metals above the ANZECC 2000 guidelines for marine aquatic ecosystems at some locations on the mainland.

For assessing the suitability for drinking water supply it is appropriate to apply the Australian Drinking Water Guidelines (NHMRC & NRMMC, 2004).

4.5.6 Groundwater Vulnerability

Published groundwater vulnerability maps of the Fitzroy Area (scale 1:400,000) and the Gladstone Area (scale 1:250,000) prepared by Queensland Department of Natural Resources and Mines (DNRM, 2002) were reviewed. These maps define the relative susceptibility of an area to groundwater pollution. Aquifers in Queensland are classified into five groundwater vulnerability classes (low, low-moderate, moderate, moderately high, and high) based on physical characteristics including recharge, aquifer media, soil media, topography, impact of the vadose zone media, and hydraulic conductivity. The mapping has been produced with regional data and the boundaries between different levels of vulnerability should not be interpreted as precise.

The Guidelines for Groundwater Protection in Australia (AWRC, 1995) suggest the following:

- *Areas of 'low' vulnerability require a groundwater contamination assessment report;*
- *Areas of 'low-moderate' vulnerability require site investigation with monitoring;*
- *Areas of 'moderate' vulnerability require detailed site investigation and monitoring;*
- *Areas of 'moderately high' vulnerability require a demonstrated groundwater protection system; and*
- *Areas of 'high' vulnerability require a desk top study, site investigations, on-going monitoring, plus a demonstrated remedial action plan for clean-up, which analyses the effectiveness of the remediation approach in achieving designated water quality criteria*.

Based on the groundwater vulnerability rating (DNRM, 2002) within the study area, the project sites are located as follows:

- LNG plant and all other Curtis Island project infrastructures - Low-Moderate Zone;
- Mainland tunnel entrance and tunnel spoil disposal area - Low-Moderate, and Moderate-High Zone;
- Launch site 1 - Low-Moderate Zone;
- TWAF 7 - Low-Moderate Zone; and
- TWAF 8 - Moderate-High Zone.

These zones can be considered an approximate indication of the susceptibility of groundwater systems to pollution.

4.6 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems are defined as ecosystems that are dependent on groundwater for their existence and health (Australian Government, 2005). This includes ecosystems in a range of environmental settings throughout the landscape. Those of relevance to the study area are described in this section.

Spring Fed Ecosystems

Springs occur under a range of circumstances – some common settings include:

- Recharge areas where water exudes from outcropping formations in upland areas, when recharge exceeds through-flow.
- Where water-bearing formations approach the ground surface in down hydraulic-gradient areas.
- At break of slope areas where a watertable intersects the ground surface.
- Where water flows to the surface through faults or fractures in overlying formations.
- Where a conduit is provided at a contact between a confining formation and an aquifer at an outcrop.

Springs commonly support groundwater dependent ecosystems, and native or endemic species can depend on the natural discharge of groundwater. Many artesian springs are known to occur within the Great Artesian Basin, where they are known as mound springs, due to the accretion of calcium carbonate, by the accumulation of aeolian sand, by the expansion of montmorillonite surface clays, and through the development of peat from spring wetland vegetation. Faunal communities endemic to these locations may be considered as groundwater dependent.

Springs of this type are not known to occur in the study area, and in addition the study area is not located within the Great Artesian Basin.

Aquateco (2011) report that no spring fed wetlands were observed and it is unlikely that aquatic communities that depend on these exist within the freshwater aquatic ecology study area (Aquateco, 2011).

Groundwater Discharge Wetlands

The 1:100,000 Queensland Wetland Map (Gladstone # 9150, DERM, 2009) shows that areas of wetland regional ecosystems include:

- “Estuarine systems”; or
- “Wetlands with oceanic water that are significantly diluted with fresh water derived from land drainage”.

These estuarine ecosystems are located in the coastal/tidal areas and are within the study area, and may be hydraulically connected to groundwater sources of fresh water. Because coastal wetlands are generally located below groundwater level, these become natural groundwater discharge areas.

Wetlands and surface water are considered in further detail in the terrestrial ecology (Ecosure 2011), freshwater aquatic ecology (Aquateco 2011) and surface water (Alluvium 2011b) technical study reports, conducted separately for this EIS.

Aquateco (2011) report that it is unlikely that aquatic communities that depend on groundwater seepage or baseflow contributions exist within the freshwater aquatic ecology study area (Aquateco, 2011).

Lakes, Streams and Estuaries

Groundwater may discharge to natural surface water bodies where surface water levels are below groundwater heads, and the strata below the river/creek bed and adjacent to the river banks are sufficiently permeable to allow seepage of groundwater.

Groundwater dependent ecosystems supported by dry season groundwater discharge or river baseflow systems include the plant and animal communities associated with ponds, river reaches and off stream billabongs and other floodplain wetlands. In addition, groundwater may support ecosystems within the streambed sediments (hyporheic zone) during periods of low flow.

Lakes, streams and estuaries are considered in further detail in the surface water technical study report (Alluvium 20011b) and marine ecology technical study report (Ecosure 2011) conducted separately for this EIS.

Phreatophytes

Phreatophytes are plant species having deep roots that obtain water from the saturated (phreatic) zone, or the partly saturated capillary zone immediately above the phreatic zone. For example, some eucalyptus tree species have well developed taproots that access groundwater as well as soil water, particularly in semi-arid to arid regions. This may include species present in the forest and woodland areas; however it is difficult to reliably establish the transpiration methods adopted specifically. Given the reasonable rainfall that occurs in the study area it may be unlikely that tree species are present that are exclusively dependent on groundwater, due to the ready availability of soil water. It is noted that no groundwater dependent ecosystems were reported in the terrestrial ecology technical study report (Ecosure 2011).

Summary of Groundwater Dependent Ecosystems in the Study Area

The following types of groundwater dependent ecosystems may potentially occur in the study area:

- Groundwater discharge wetlands;
- Lakes, streams and estuaries;
- Phreatophytes; and
- Spring fed ecosystems.

Spring fed systems have not been identified, but could occur in some settings such as break of slope areas.

The other ecosystem types are known to occur in the study area and the project has the potential to impact upon them. These include in particular groundwater discharge wetlands, and lakes streams and estuaries in lower lying areas. Potential impacts to phreatophytes are most likely to occur as a result of groundwater dewatering (lowering watertables) or reduced recharge (also leading to lowering watertables). However, groundwater extraction is not planned and the likely location of lowered watertables (should they occur) is limited to down-gradient of the LNG plant where phreatophytes may not occur.

5 ENVIRONMENTAL VALUES

This section identifies and discusses the groundwater environmental values of the study area.

In many cases, the attributes of a groundwater system are such that it is relied upon to provide groundwater for a variety of extractive uses, to support areas of biological importance, or for human interest. The enhancement and protection of these aspects of groundwater reliance are required in the Environmental Protection (Water) Policy 2009 (EPP (Water) Policy).

The attributes of the study area groundwater systems lead to the groundwater environmental values, and influence the sensitivity of the groundwater system (i.e. how the system responds to disturbance).

How the groundwater system responds to disturbance is controlled by a combination of the fundamental characteristics of the groundwater system (for example water chemistry, transmissivity, storativity and extent) and the hydrogeologic processes acting on the groundwater systems (for example recharge and discharge).

5.1 Assessment of Values to be Protected

The EPP (Water) Policy provides a framework for identifying the environmental values, and establishing water quality guidelines and objectives to enhance or protect Queensland waters. For the purposes of this assessment, the “values” as defined in the EPP (Water) Policy are used to define those attributes of the groundwater system within the study area that are important, because these are the attributes that allow the groundwater to be relied upon in this way.

This section of the assessment presents the environmental values (as summarised from the EPP (Water) Policy) that govern how the groundwater system within the study area is to be protected or enhanced.

Although no grouping is provided in the policy, for discussion purposes it is convenient to characterise a groundwater system in a way that indicates its suitability to:

- Support biological areas;
- Support recreation or aesthetic uses;
- Allow consumptive or productive uses; and
- Support areas of anthropomorphic importance.

The identified groundwater uses listed above are presented in the following sub-sections, identifying environmental values, and with comments and notes of relevance for application to the groundwater system in the study area.

Groundwater to Support Biological Areas

As defined in the EPP (Water) Policy, for groundwater systems that support biological areas, the biological environmental values to be protected are:

Value 1: Biological integrity of a pristine or modified aquatic ecosystem that is effectively unmodified or highly valued. (For high ecological value waters).

Value 2: Biological integrity of an aquatic ecosystem that is affected adversely to a relatively small but measureable degree by human activity. (For slightly disturbed to moderately disturbed waters).

Value 3: Biological integrity of an aquatic ecosystem that is measurably degraded and of lower ecological value that waters mentioned in 1) and 2) above. (For highly disturbed waters).

Groundwater systems may be considered to support biological areas where the groundwater supports an aquatic ecosystem either directly or indirectly. For example, where an aquifer discharges to a spring system then the groundwater system may be directly supporting an ecosystem. Where an aquifer discharges to a wetland, lake or stream, then the groundwater system may be indirectly supporting an ecosystem. The biological integrity of such ecosystems would require protection at levels dependent on the ecological value of the groundwater. For the purpose of assessing environment values and assessing the ecological value of waters (as relevant to groundwater) the aspects presented in Table 5.1 have been considered.

Table 5.1: Groundwater aspects influencing ecological value of waters

Aspect	Comments
Chemistry	Aspects of the water chemistry (for instance high salinity) would reduce the ecological value of groundwater if it were discharging to a low salinity surface feature (e.g. fresh wetland, stream, etc). However the same groundwater might have high ecological value where discharging to a naturally saline wetland system.
Discharge to surface water	Groundwater systems that interact with surface ecosystems potentially have high ecological value. Deeper confined and isolated groundwater systems that do not interact with surface water may have lower intrinsic ecological value.
Isolation from human processes	Groundwater systems in remote, forested or undeveloped areas are less likely to be disturbed or impacted by human processes, and may have higher ecological values.
Wetlands, lakes and Streams	Within the study area a range of groundwater/surface-water interaction is expected to occur. In some cases this will result in groundwater discharge (baseflow) to surface water features, and biological features will require protection, depending on the ecological value of the groundwater system.
Springs	Discharge springs have not been identified within the study area, although it is possible that some minor springs are present.

Values to support recreation or aesthetic uses

As defined in the EPP (Water) Policy, water systems that support human interaction through recreation or aesthetic uses can be further characterised as displaying attributes that support the following environmental values:

Value 4: Primary recreational use.

Value 5: Secondary recreational use.

Value 6: Visual recreational use.

This category of water use and reliance is applicable to surface water features which are accessible either for recreational use or for visual interaction, and not relevant to groundwater. Hence, they are not considered further in this report.

Groundwater for consumptive or productive uses

As defined in the EPP (Water) Policy, groundwater systems that support consumptive or productive uses can be further characterised as displaying attributes that support the following environmental values:

Value 7: Minimal treatment before supply as drinking water.

Value 8: Use in agriculture.

Value 9: Use in aquaculture, and producing aquatic food for human consumption.

Value 10: Suitability for industrial uses.

<u>Potable Uses</u>. The spatial variability of water quality means that the suitability of groundwater for potable supply will be, in many cases, location specific. In the study area, groundwater is recognised to range from marginal fresh, through brackish to saline and may vary widely across short distances, especially in coastal locations.

<u>Non-Potable Uses</u>. A significant portion of the non-potable groundwater in the region is suitable for (and used for) irrigation and stock purposes.

Aquaculture and the production of aquatic food for human consumption are viable uses for brackish and saline waters although the water quality parameters for these uses are often highly process specific. Aquaculture uses have not been identified in the study area, but are feasible.

The groundwater may also be suitable for a range of industrial processes including cooling water, process water, utility water and wash water. As industrial processes require particular water quality, specific hydrochemical data is normally required to evaluate suitability for a specific industrial use.

Groundwater to support areas of anthropomorphic importance

As defined in the EPP (Water) Policy, groundwater systems that support areas of anthropomorphic importance can be further characterised as displaying attributes that support the following:

Value 11: Cultural and spiritual values.

The characteristics of groundwater systems that support areas of anthropomorphic importance would relate to physical features where groundwater interaction can occur, such as wells and springs having anthropological, archaeological, historic, sacred or scientific significance.

Artesian conditions can lead to permanent water pools and springs and if present could have cultural significance. However artesian discharge springs are unknown in the study area and it is unlikely that they occur.

5.1.1 Identified Environmental Values

Based on the results of the desktop study (refer section 4.4, Groundwater Resources) groundwater within the study area can be characterised as poor quality and varying from marginal fresh, through brackish to saline water types (see Figure 4.1b), and with elevated metal concentrations. Based on data from boreholes located within and in the vicinity of the Arrow LNG Plant study area (refer section 4.4) the groundwater resources are limited with most recorded bore yields less than 5 L/s.

The relevant aspects of the groundwater resources in the study area underpin the assessment of environmental values are as follows:

- The groundwater quality is generally not suitable for drinking water purposes without treatment.
- The groundwater has limited potential use for stock watering.
- The suitability of groundwater for aquaculture and production of aquatic food for human consumption is limited due to low sustainable bore yields.
- The groundwater quality may be suitable for specific industrial uses. Industrial processes may require particular limits on the concentration of some parameters, and Industrial uses may be limited due to low sustainable bore yields.
- The existing groundwater discharge into the receiving ecosystems has concentrations of some parameters that exceed the ANZECC guidelines for Freshwater and Marine Ecosystems.
- Groundwater related sites such as springs and wells having cultural and spiritual values have not been identified.

Tables 5.2a and 5.2b provide an assessment of environmental values of the study area based on groundwater system characteristics, properties and processes, for the alluvial/colluvial and bedrock groundwater systems respectively.

Table 5.2a – Environmental Values of the Study Area: Groundwater System Characteristics, Properties and Processes – Alluvial and Colluvial Aquifers

		ENVIRONMENTAL VALUES TO BE PROTECTED										Intrinsic Groundwater Properties
		[1]BIOLOGICAL AREAS			CONSUMPTIVE AND PRODUCTIVE USES						ANTHROPO-MORPHIC	
AQUIFER SYSTEM	ECOLOGICAL IMPORTANCE	**High Ecological Value Waters**	**Slightly to Moderately Disturbed Waters**	**Highly Disturbed Waters**	**Potable Supply**	**Agricultural Use**	**Stock Watering**	**[3]Aqua-culture**	**Producing Aquatic Food for Human Consumption**	**Industrial Use**	**Cultural & Spiritual Values of the Water**	Groundwater yields generally low in bedrock geology. Isolated but localised occurrences of high yielding zones possible. **Biological Values** The confined bedrock aquifers are not associated with sensitive groundwater dependent ecosystems. **Consumptive and Productive Use Values** Based on TDS water has a limited range of uses. Potable occurrences are marginal in quality, localised, and yields are low. **Anthropomorphic Values** No groundwater sites with cultural or spiritual values identified.
Alluvial & Colluvial Aquifers (Unconfined)	MODERATE	Some areas	Most areas	Some areas	Limited to isolated areas	Limited to isolated areas	Some areas	Some areas	Limited to isolated areas	Some areas	Not identified	
Alluvial & Colluvial Aquifers (Confined)	MODERATE	Some areas	Not expected	Not expected	Limited to isolated areas	Limited to isolated areas	Some areas	Some areas	Limited to isolated areas	Some areas	Not identified	

1. The biological environmental values of water to be protected under the Environmental Protection (Water) Policy 1997 include:
    - For high ecological value waters –***The biological integrity of an aquatic ecosystem that is effectively unmodified or highly valued***; and
    - For slightly modified disturbed waters – ***The biological integrity of an aquatic ecosystem that is affected adversely to a relatively small but measurable degree by human activity***; and
    - For highly disturbed waters – ***The biological integrity of an aquatic ecosystem that is measurably degraded and of lower ecological value than waters mentioned above***.
    - Spring complexes should be considered under biological and anthropomorphic values.

Table 5.2b – Environmental Values of the Study Area: Groundwater System Characteristics, Properties and Processes – Bedrock Aquifers

		ENVIRONMENTAL VALUES TO BE PROTECTED										Intrinsic Groundwater Properties
		BIOLOGICAL AREAS			CONSUMPTIVE AND PRODUCTIVE USES						ANTHROPO-MORPHIC	
AQUIFER SYSTEM	ECOLOGICAL IMPORTANCE	**High Ecological Value Waters**	**Slightly to Moderately Disturbed Waters**	**Highly Disturbed Waters**	**Potable Supply**	**Agricultural Use**	**Stock Watering**	**[3]Aqua-culture**	**Producing Aquatic Food for Human Consumption**	**Industrial Use**	**Cultural & Spiritual Values of the Water**	Groundwater yields generally low in bedrock geology. Isolated but localised occurrences of high yielding zones possible. **Biological Values** The confined bedrock aquifers are not associated with sensitive groundwater dependent ecosystems. **Consumptive and Productive Use Values** Based on TDS water has a limited range of uses. Potable occurrences are marginal in quality, localised, and yields are low. **Anthropomorphic Values** No groundwater sites with cultural or spiritual values identified.
Bedrock Aquifers (Unconfined)	MODERATE	Some areas	Most areas	Not expected	Limited to isolated areas	Limited to isolated areas	Some areas	Limited to isolated areas	Limited to isolated areas	Some areas	Not identified	
Bedrock Aquifers (Confined)	LOW	Some areas	Not expected	Not expected	Some areas	Some areas	Some areas	Limited to isolated areas	Some areas	Some areas	Not identified	

1. The biological environmental values of water to be protected under the Environmental Protection (Water) Policy 1997 include:
   - For high ecological value waters –***The biological integrity of an aquatic ecosystem that is effectively unmodified or highly valued***; and
   - For slightly modified disturbed waters – ***The biological integrity of an aquatic ecosystem that is affected adversely to a relatively small but measurable degree by human activity***; and
   - For highly disturbed waters – ***The biological integrity of an aquatic ecosystem that is measurably degraded and of lower ecological value than waters mentioned above***.
   - Spring complexes should be considered under biological and anthropomorphic values.

5.1.2 Spatial and Non-Spatial Environmental Values

The identified groundwater values include those having a spatial component and also those that are unconstrained spatially.

Groundwater attributes that support biological areas are an example of environmental values that can be spatially constrained. For example, high ecological value groundwater systems (such as undisturbed waters) could be mapped if sufficient data were available, and constraints applied to development in areas of high ecological importance.

Anthropomorphic areas are also constrainable by mapping those sites or areas of cultural and spiritual value, although such have not been identified in the study area.

The groundwater attributes that define consumptive and productive uses (for example TDS or salinity) are widely applicable to groundwater. It is not practical to constrain these based on spatial factors, because the requirement to protect these uses as they relate to groundwater at any location is dependent of the site-specific value. Because of this, controls may also be site specific.

5.1.3 Summary

As defined in Table 5.2 and in conjunction with the EPP (Water) Policy, groundwater systems present within the study area are characterised by attributes that (where the environmental value is identified) may support:

- Biological integrity of an aquatic ecosystem that is affected adversely to a relatively small but measureable degree by human activity. (Slightly to moderately disturbed waters – for example agricultural areas).
- Biological integrity of an aquatic ecosystem that is measurably degraded and of lower ecological value than waters mentioned in 1) and 2) above. (Slightly to moderately disturbed waters – for example locations near urban or industrially development).
- Minimal treatment before supply as drinking water.
- Use in agriculture/stock watering.
- Use in aquaculture, and producing aquatic food for human consumption.
- Suitability for industrial uses.

Attributes supporting these uses or environment values are not indicated to be ubiquitous and cannot be constrained by mapping due to limited available data.

Accordingly, the sustainable function and use of, and dependence upon, groundwater resources within the study area would require protection of the attributes of the groundwater systems that support/enable these uses only where identified to occur. Table 5.2 indicates the assessed applicability according to aquifer occurrence and this is considered further in Section 7 on a location specific basis for impact assessment.

5.2 Environmental values – sensitivity classification

The impact assessment methodology (Section 3) requires that the sensitivity of the environmental values is assessed, as this is a necessary factor in the significance assessment conducted in Section 7.

To assess the sensitivity of environmental values, a rating scheme must be applied to the values.

In the process adopted, the sensitivity of an environmental value is determined from its intrinsic characteristics, or susceptibility to threatening processes. This requires the establishment of a sensitivity classification scheme.

Table 5.3 presents the sensitivity classification scheme, and shows the criteria adopted for assessing the sensitivity of the groundwater systems. The sensitivity criteria adopted have been chosen to encompass those features of a groundwater system that characterise it sufficiently to understand and classify the environmental and physical aspects of the system, with consideration of the EPP (Water) Policy.

Table 5.3: Groundwater system sensitivity classification criteria

Sensitivity Criteria	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Conservation status elements of the groundwater system as defined by statutory and regulatory authorities. This is related to the suitability of the water to support: • Biological areas • Consumptive and productive uses • Anthropomorphic areas	Attributes of the groundwater system are unsuitable for prescribed uses as defined in the EPP (Water) Policy	Attributes of the groundwater system are of low ecological importance, and are characterised as highly disturbed waters as defined in the EPP (Water) Policy	Attributes of the groundwater system are of low to moderate ecological importance, and are characterised as slightly to moderately disturbed waters as defined in the EPP (Water) Policy. Intrinsic attributes support the use of the groundwater for: • Stockwatering • Industrial uses	Attributes of the groundwater system are of high ecological importance, as defined in the EPP (Water) Policy Intrinsic attributes support the use of the groundwater for: • Aquaculture	Attributes of the groundwater system are of high ecological importance, as defined in the EPP (Water) Policy Intrinsic attributes support the use of the groundwater for: • Potable supply • Agricultural use • Production of aquatic food for human consumption
Rarity of occurrence, abundance or distribution of groundwater system or aquifer type and availability of equivalent or representative alternatives	Attributes of the groundwater system are ubiquitous.	Attributes of the groundwater system are common on a local, regional and national basis,and therefore, have locally available alternatives	Attributes of the groundwater system are locally unique, but have regionally available alternatives	Attributes of the groundwater system are locally unique. But with few regionally available alternatives	Attributes of the groundwater system are unique. There are no known available alternatives
Resilience to change (i.e. groundwater properties such as water level or pressure changes, porosity reduction)	Intrinsic properties of the groundwater system are resilient to change, as a result of dewatering, for example	Intrinsic properties of the groundwater system are slighly rigid to change, as a result of dewatering, for example. However, the overall function of the groundwater system remains relatively unchanged	Intrinsic properties of the groundwater system are moderately susceptible to change, as a result of dewatering, for example. The overall function of the groundwater system could be moderately altered	Intrinsic properties of the groundwater system are susceptible to change, as a result of dewatering, for example. The overall function of the groundwater system would be temporarily altered	Intrinsic properties of the groundwater system are very susceptible to change, as a result of dewatering, for example. The overall function of the groundwater system would be permanately altered
Dynamicism of existing environment (i.e. hydrogeologic processes)	Groundwater systems with very high recharge rates and very short recovery periods	Groundwater systems with high recharge rates and short recovery periods	Groundwater systems with moderate recharge rates and medium term recovery periods	Groundwater systems with low recharge rates and slow recovery periods	Groundwater systems with very low recharge rates and very slow recovery periods
Rehabilitation potential	Rehabilitation can be successfully achieved in all cases	Rehabilitation can be successfully achieved in the majority of cases	Rehabilitation is likely to be slow or only partially successful	Rehabiliitation potential is limited or only successful in the minority of cases	Extremely limited rehabilitiation potentail if impact on the value can not be avoided

A groundwater sensitivity weighting (derived from Table 5.3) was assigned to each environment value grouping and criteria in Table 5.4, depending on its assessment of very high, high, moderate, low or very low sensitivity (5, 4, 3, 2 or 1 respectively).

The weightings assigned to each were then summed to rank each groundwater system, and assign an overall sensitivity classification that considers the environment values. This groundwater sensitivity classification underpins the impact assessment in the following sections, and provides a linkage between impacts to groundwater systems and the environment values associated with the groundwater systems.

The overall sensitivity rankings take into consideration the intrinsic properties and geologic/hydrogeologic processes that influence the way a groundwater system responds to an impact as described below.

Overall characteristics/features of the alluvial/colluvial groundwater systems

The alluvial/colluvial groundwater systems are considered to have the following general characteristics for assessment of sensitivity:

- Ranges from marginally potable to saline water quality.
- Of regional extent. These aquifers are common in many areas.
- Shallow alluvial/colluvial groundwater systems are recharged regularly predominantly through rainfall processes, and are resilient to groundwater drawdown.
- Dynamic processes such as diffuse rainfall recharge are likely to enable rapid groundwater level recoveries where drawdown occurs.
- Where unconfined, rehabilitation can be achieved readily when impacts are removed.
- Where confined, groundwater systems are at lower risk of contaminant impact from surface processes.

Overall characteristics/features of the bedrock groundwater systems

- Ranges from marginally potable to saline water quality.
- Of regional extent. These aquifers are common in many areas.
- Shallow bedrock groundwater systems are recharged regularly predominantly through rainfall processes, and are resilient to groundwater drawdown.
- Deeper bedrock groundwater systems are recharged regularly predominantly through rainfall processes in upland outcrop areas or inter-aquifer leakage, and can be resilient to groundwater drawdown depending on parameters.
- Dynamic processes such as diffuse rainfall recharge (where shallow) are likely to enable rapid groundwater level recoveries where drawdown occurs.
- Where unconfined, rehabilitation can be achieved readily when impacts are removed.
- Where confined, groundwater systems are at lower risk of contaminant impact from surface processes.

Table 5.4: Assessment of groundwater sensitivity within the study area

GROUNDWATER SYSTEM TYPE	CONSERVATION STATUS ELEMENTS[1]			RARITY	RESILIENCE	DYNAMICISM	REHABILITATION POTENTIAL	SENSITIVITY RANKING	CLASSIFICATION
	BIOLOGICAL	CONSUMPTIVE AND PRODUCTIVE USE	ANTHROPOMORPHIC						
ALLUVIAL/COLLUVIAL SYSTEMS (Unconfined settings)	5	1	1	1	1	1	1	11	LOW
ALLUVIAL/COLLUVIAL SYSTEMS (Confined settings)	2	2	1	1	2	2	3	13	LOW
BEDROCK SYSTEMS (Unconfined settings)	4	3	1	1	2	1	2	14	LOW
BEDROCK SYSTEMS (Confined settings)	2	4	1	1	3	2	3	16	MOD
Groundwater Sensitivity Weighting: Very High = 5, High = 4, Moderate = 3, Low = 2, Very Low = 1 **Sensitivity Classification**: Very Low = <10, Low = 10 - 15, Moderate = 16 - 20, High = 21 – 25, Very High = >25									

1) Refer Table 5.3

6 POTENTIAL IMPACTS

The project has the potential to cause impacts to the groundwater systems through activities associated with the project construction, operation and decommissioning phases.

Impact assessment is used to determine the potential threat that project activities pose to the groundwater systems, and the environmental values linked to those systems (identified in Section 5) within the areas of disturbance caused by the project.

Potential groundwater related impacts associated with the project include:

1) Impacts caused by construction and operation of the LNG plant;
2) Impacts caused by construction and operation of the feed gas pipeline and tunnel;
3) Impacts caused by construction and operation at the temporary workers accommodation facilities;
4) Impacts caused by the construction and operation of the launch sites;
5) Impacts caused by decommissioning of infrastructure; and
6) Cumulative impacts caused by other activities associated with the project.

The potential impacts associated with the project, including the likely magnitude of the impacts (assuming they occur) are identified in this section. The significance of impacts and mitigation measures are discussed in Section 7. Cumulative impacts are considered separately in Section 9.

The magnitude of impacts has been rated with consideration of the criteria in Table 6.1. These ratings are then used in the significance assessment in Section 7.

Table 6.1: Impact magnitude rating criteria

Magnitude Rating	Rank	Criteria
Very Low	1	Impact is restricted to within the area of activity or footprint. No short-term or long-term project impacts likely to environmental values.
Low	2	Some minor project impacts likely to environmental values, but such impacts likely for short duration only, with rapid recovery following end of impacting activity. Impact may extend beyond the area of activity or footprint, but is localised. Where impact is to an aquifer: • the impact is restricted to within that aquifer only; and • other aquifers or groundwater discharge features are not affected.
Moderate	3	Some minor project impacts likely to environmental values, but such impacts likely to persist over time. Or… Some moderate project impacts likely to environmental values, but such impacts likely short duration only, with rapid recovery following end of impacting activity. Impact extends beyond the area of activity or footprint. Where impact is to an aquifer: • the impact may occur across aquifers; or • groundwater discharge features may be affected.
High	4	Some moderate project impacts likely to environmental values, but such impacts likely to persist over time. Or… Some major project impacts likely to environmental values, but such impacts likely short duration only, with rapid recovery following end of impacting activity. Impact extends across significant areas. Where impact is to an aquifer: • the impact occurs across aquifers; and • groundwater discharge features are affected.
Very High	5	Some irreversible or persistent major project impacts likely to environmental values. No recovery from such impacts in the foreseeable future. Impact extends across regional areas. Where impact is to an aquifer: • the impact occurs across aquifers regionally; and • groundwater discharge features are affected at a regional scale or in multiple locations.

6.1 LNG Plant Development Associated Impacts

The potential impacts on groundwater values caused by the construction, operation and decommissioning of the LNG plant on Curtis Island are discussed below, and summarised in Table 6.2. Table 6.2 provides a linkage between the environment values and identified impacts.

Reduced aquifer recharge

The clearing of vegetation, resurfacing with impermeable materials and ground compaction during construction of the LNG plant, may reduce infiltration rates and recharge to the shallow unconfined groundwater systems in the study area on Curtis Island.

However changes to overall groundwater recharge caused by land use change is envisaged to be of low significance due to the relatively small area of aquifer affected, compared to the aquifer extent. In addition, it is likely that the bulk of aquifer recharge would occur in upland locations on Curtis Island beyond the immediate LNG plant footprint. Because of this the magnitude of impact (Table 6.1), assuming it occurs, will be very low.

Altered aquifer characteristics

The development of the LNG plant and associated infrastructure may cause compaction of the underlying unconfined shallow aquifers, thereby potentially altering the hydrogeological characteristics (i.e. porosity, permeability, structure). This may affect the groundwater flow, levels and gradients. However compaction is likely to be limited, and because the extent of the area affected is small in comparison to the aquifer (within the area of activity or project footprint) the magnitude of impact, assuming it occurs, is considered to be very low.

Degradation of groundwater quality through disturbance to acid sulfate soils

The construction of Boatshed Point MOF 1, Boatshed Point haul road, LNG jetty in North China Bay, MOF at Hamilton Point and other infrastructure will occur in low-lying areas where marine/estuarine sediments may generate acid from oxidation of sulphide minerals in the potential acid sulfate soils (ASS). This may cause the acidification and degradation of shallow groundwater quality. The resultant low pH conditions could also lead to the mobilisation of metals in groundwater and subsequent discharge to the sea. Moderate impacts are indicated based on the criteria in Table 6.1.

The potential impacts of ASS are specifically addressed in the separate technical study ‘Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.

Contamination of groundwater systems – spills and leaks

The potential exists for degradation of shallow groundwater quality in the vicinity of the LNG plant as a result of unintentional spills and leaks. These leaks may originate from:

- Petroleum based fuels used by excavators and construction machinery.
- Chemicals and waste waters, including by-products (brine) from desalination processes.
- Sanitation and domestic waste systems.

Workshop areas, vehicle and equipment wash-down or laydown areas, and equipment and machinery repair areas all have the potential to spill fuels, lubricants, solvents, or other hazardous products.

These impacts could occur onsite, and the magnitude of the impacts if they occur is likely to be moderate because impacts to environmental values could persist over time (Table 6.1).

Seepage of brine from Reverse Osmosis (RO) plant

Potential impacts relating to storage and handling of brine water as a result of the reverse osmosis plant could occur. Brine will be discharged from the plant to the harbour, with limited or transient site storage.

The potential magnitude of impact is considered moderate (Table 6.1) because the brine water could migrate off site during leakage.

Impacts to groundwater dependent ecosystems

Groundwater dependent ecosystems in discharge wetlands, streams and estuaries in the lower lying areas may be affected by the LNG plant development. Contaminated groundwater due to spills and leaks may potentially migrate and affect any ecosystems present. These impacts could occur onsite and offsite, and the magnitude of the impacts if they occur is likely to be moderate based on the criteria in Table 6.1.

Excavation activities - dewatering

Dewatering during excavation activities may generate significant volumes of poor quality water on site and may alter groundwater flow patterns. Excavation activities also have the potential to cause deterioration in groundwater quality due to the exposure of acid sulfate soils where they occur. Impacts may include saline intrusion, and groundwater quality impacts due to acid sulfate soils.

These impacts could occur both onsite and offsite, however the magnitude of the impacts if they occur is likely to be low because some minor project impacts could impact environmental values, but such impacts would be likely for a short duration only, with rapid recovery following end of impacting activity.

Vertical migration of contaminants to deeper groundwater system

The potential exists for contaminated groundwater in the vicinity of the LNG plant in shallow aquifers as a result of (for example) unintentional spills and leaks, and this could feasibly migrate to deeper groundwater systems which are more difficult to remediate.

Some impacts could occur to environmental values, but such impacts would be expected to have a short duration only, with rapid recovery following end of impacting activity. Some impact could occur across aquifers. Hence, based on Table 6.1 the impact is assessed as moderate.

6.2 Feed Gas Pipeline and Tunnel

The potential impacts on groundwater values caused by the construction, operation and decommissioning of the feed gas pipeline and tunnelling are discussed below, and summarised in Table 6.2.

The feed gas pipeline from the proposed Arrow Surat Pipeline to the tunnel launch shaft will be constructed using conventional open-cut trenching methods within a 40 m wide construction right of way. The feed gas pipeline from the tunnel received shaft on Hamilton Point to the LNG plant will be constructed using conventional open-cut trenching methods within a 30 m wide construction right of way. It is planned that the trench will be 2 m deep and 1.2 m wide.

The tunnel under Port Curtis will have an excavated diameter of up to ~5.65 m and will be constructed via mechanised tunnel boring techniques. Tunnel spoil material will be processed through a de-sanding plant to remove the bentonite and water and will comprise mainly a finely graded fill material, which will be deposited in a spoil placement area established within bund walls constructed adjacent to the launch shaft. Based on the excavated diameter, approximately 223,000 m^3 of spoil will be treated as required for acid sulfate soil and disposed of at this location.

The pipeline depth is not likely to result in impacts to groundwater flow directions due to the shallow emplacement depth where land traverses occur. Where the pipeline is emplaced in a tunnel beneath the harbour the infrastructure will predominantly be within sub-sea groundwater conditions. Impact to shallow coastal groundwater systems is unlikely.

In addition, the tunnel will be designed and constructed for dry operations (‘tanked’ tunnel design) and there will be no groundwater drawdown associated with the tunnel once commissioned.

Reduced aquifer recharge

The clearing of vegetation, resurfacing with impermeable materials and ground compaction during construction of the pipeline and tunnelling may reduce infiltration rates and recharge to the shallow unconfined groundwater systems, however the actual area of these disturbances is low.

Any changes to overall groundwater recharge are envisaged to be small due to the relatively small area of aquifer affected, compared to the aquifer extent. Because of this, based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be very low.

Altered aquifer characteristics

Pipeline trenching and tunnelling could alter aquifer characteristics on local scales. However the area and depth of disturbances are limited, and the extent of the area affected is small in comparison to the aquifer. Because of this, based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be very low.

Groundwater impacts from dewatering

The possible impacts of the dewatering associated with the trenching, feed gas pipeline installation and tunnelling, together with the assessed magnitude, in relation to groundwater contamination include:

- The alteration of recharge (increased) along the trench (localised within the area of activity). Based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be low.
- Saline intrusion to fresher aquifers due to dewatering of trench excavations. Based on the criteria in Table 6.1 the magnitude of impact, if realised, could be high.
- The alteration of permeability, porosity, and storage within the trench (altered soil/regolith within the area of activity). Based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be very low.
- Alterations in shallow groundwater flow patterns localised along the trench (within or near to the area of activity). Based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be low.
- Temporary reduction of groundwater levels by dewatering during the installation of the feed gas pipeline (within or localised near the area of activity). Based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be low.

Altered groundwater flow system due to tunnelling, causing saline intrusion

Altered groundwater flow system due to tunnelling, including the potential for saline-water intrusion during dewatering activities in close vicinity to the coast (may extend beyond the area of activity and may be some moderate impacts to environment values). Based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, could be moderate, however it is recognised that in the area of impact any groundwater may have little or no practical beneficial use.

Because the tunnel will be designed and constructed for dry operations there will be no ongoing groundwater drawdown associated with the tunnel once commissioned.

Degradation of groundwater quality through disturbance to acid sulfate soils

Excavation will occur in low-lying areas where marine/estuarine sediments may generate acid from oxidation of sulphide minerals in the potential acid sulfate soils. This may cause the acidification and degradation of shallow groundwater quality. The resultant low pH conditions could also lead to the mobilisation of metals in groundwater and subsequent discharge to the sea. High impacts are indicated.

The potential impacts of ASS are specifically addressed in the separate technical study ‘Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.

Contamination of groundwater systems from spills and leaks of petroleum and chemicals

The possible impacts of the trenching, feed gas pipeline installation and tunnelling on the groundwater systems together with the assessed magnitude, in relation to groundwater contamination include:

- Contamination of the shallow groundwater system from drilling fluids (moderate magnitude impact because some project impacts likely to environmental values that could persist over time).
- Contamination of shallow groundwater from chemicals and hydrocarbons, including fuels and lubricants (moderate magnitude impact because some project impacts likely to environmental values that could persist over time).

Vertical migration of contaminants to deeper groundwater system

The potential exists for contaminated groundwater in shallow aquifers in the vicinity of trenching or tunnelling operations as a result of (for example) unintentional spills and leaks. Contaminated shallow groundwater could feasibly migrate to deeper groundwater systems which are more difficult to remediate.

These impacts could occur both onsite and offsite and across aquifers. Based on the criteria in Table 6.1, the magnitude of the impacts if they occur is hence assessed as moderate.

6.3 TWAF 7, TWAF 8 and Launch Site 1

The potential impacts on groundwater values caused by the construction, operation and decommissioning of the TWAFs and Launch Site 1 are discussed below, and summarised in Table 6.2.

Two workforce construction camp locations are proposed: the main construction camp at Boatshed Point on Curtis Island, and a possible mainland overflow construction camp, referred to as a temporary workers accommodation facility (TWAF). Two potential locations are currently being considered for the mainland TWAF.

TWAF 7 is located on estuarine mudflats on the former Gladstone Power Station ash pond No.7, and TWAF 8 is located in the vicinity of Targinnie on a primarily cleared pastoral grazing lot. The area of disturbance for TWAF 7 is 26.5 ha, and for TWAF 8 the area is 31.7 ha.

The mainland launch site (Launch Site 1) will be located on estuarine mudflats on the eastern bank of the Calliope River, close to the river mouth. The area of this site is 20.8 ha. Part of this site comprises reclaimed land with anthropogenic fill (Figure 1.1) and ash settling ponds. The groundwater system is likely to be highly disturbed as a result. Launch Site 1 and TWAF 7 have similar site settings and hence similar potential impacts. Because of this, the impact assessment considers these sites together.

Although contaminants have not been identified at TWAF 7 and Launch Site 1 (where ash ponds have been present historically), potential chemicals of concern (COPC) that may exist at these sites (and in groundwater) include petroleum hydrocarbons, polycyclic aromatic hydrocarbons, metals and polychlorinated biphenyls (Coffey Environments, 2011a).

The potential groundwater impacts associated with the construction and operation of the temporary workers accommodation facilities and Launch Site 1 are described below:

Reduced aquifer recharge

The clearing of vegetation, resurfacing with impermeable materials and ground compaction during construction of the temporary workers facilities, may reduce infiltration rates and recharge to the shallow unconfined groundwater systems, however the actual area of these sites is small.

Any changes to overall groundwater recharge caused by land use change are envisaged to be small due to the relatively small area of aquifer affected, compared to the aquifer extent. The bulk of aquifer recharge is likely to occur in upland locations on the mainland beyond the footprint of these sites.

Any changes to overall groundwater recharge caused by land use change are envisaged to be small due to the relatively small area of aquifer affected, compared to the aquifer extent. Because of this, based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be very low.

Altered aquifer characteristics

The development may cause compaction of the underlying unconfined shallow aquifers, thereby potentially altering the hydrogeological characteristics (i.e. porosity, permeability, structure). This may affect the groundwater flow, levels and gradients. However compaction is likely to be limited, the extent of the area affected is small in comparison to the aquifer, and depth of disturbance would be limited.

Because of this, based on the criteria in Table 6.1 the magnitude of impact, assuming it occurs, will be very low.

Degradation of shallow groundwater quality from leaks and spills of sanitation systems

Leaks from sanitation systems and potential spills during the management of waste from sanitation systems have the potential to degrade groundwater quality in shallow aquifers. At the TWAF sites, the duration of site use is short, and assuming the impact occurs the magnitude will be low.

At Launch Site 1 a longer operational duration would increase the duration of impacts. Based on the criteria in Table 6.1 the impact is assessed as moderate because some project impacts are likely to environmental values that could persist over time.

Contamination of groundwater systems from spills and leaks of petroleum and chemicals

Unintentional spills and leaks would reach shallow groundwater and degrade its quality in the vicinity of the TWAFs and Launch Site 1. These leaks may originate from:

- Petroleum based fuels used by excavators and construction machinery.
- Chemicals and waste waters.

At the TWAF sites these impacts could occur onsite, and the magnitude of the impacts if they occur is likely to be moderate because impacts to environmental values could persist over time (Table 6.1).

At Launch Site 1 the more limited laydown area site operation indicates that any impacts would be localised and lower in magnitude than for the TWAF laydown areas, and hence based on the criteria in Table 6.1 the magnitude is assessed as low.

Degradation of groundwater quality through disturbance to acid sulfate soils

The construction of TWAF 7 and Launch Site 1 near the low-lying areas along Auckland Creek may generate acid groundwater conditions due to exposure of acid sulfate soils.

Proposed facility TWAF 8 is located at an elevation of greater than 20 mAHD. Acid sulfate soils should not pose a hazard at this location (Coffey Geotechnics, 2011b).

The potential impacts of ASS are specifically addressed in the separate technical study ‘Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.

Impact to groundwater dependent ecosystems

Reduced groundwater flows due to changes in aquifer characteristics, or contaminated groundwater due to spills and leaks, may all potentially affect groundwater dependant ecosystems. Auckland Creek, the Calliope River and estuaries lie in close proximity to the proposed TWAF 7 and Launch Site 1.

Based on topography and position in the landscape, groundwater in shallow alluvial aquifers at TWAF 7 and Launch Site 1 would be expected to discharge at the coast and estuaries and into streams as baseflow. For TWAF 8, groundwater may flow through the sub-surface off-site, although baseflow discharge to the local stream is feasible. The full nature of groundwater/surface water interaction is not known for this site.

Contaminated groundwater due to spills and leaks may potentially affect any ecosystems present. Some impacts could occur to environmental values onsite and offsite, and such impacts could persist over time. Hence, based on the criteria in Table 6.1 the magnitude of the impacts if they occur is likely to be moderate.

Vertical migration of contaminants to deeper groundwater system

The potential exists for contaminated groundwater in shallow aquifers beneath the TWAFs and Launch Site 1 as a result of (for example) unintentional spills and leaks. Contaminated shallow groundwater could feasibly migrate to deeper groundwater systems which are more difficult to remediate.

These impacts could occur both onsite and offsite and across aquifers. Based on the criteria in Table 6.1, the magnitude of the impacts if they occur is hence assessed as moderate.

6.4 Decommissioning

All facilities will be decommissioned at some undetermined future time. The potential impacts on groundwater values caused by the decommissioning include those impacts already identified in sections 6.1 to 6.3 (relating to construction and operation) but also will include those impacts discussed below, and summarised in Table 6.2.

Additional potential groundwater impacts associated with decommissioning include contamination from the management and handling of waste and materials during this phase. In addition, onsite monitoring wells and bores will require decommissioning.

The magnitude of impacts assuming the presence of hazardous materials onsite without adequate management is considered to be moderate (Table 6.1) because some moderate impacts to environment values could occur but such impacts would be expected to have a short duration only with rapid recovery following decommissioning.

Table 6.2: Summary of identified impacts and assessed magnitude

LNG Plant			
Environmental Values Affected	**Sensitivity Classification[1]**	**Identified Impact**	**Assessed Magnitude**
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Reduced aquifer recharge	Very Low
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Altered aquifer characteristics	Very Low
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Degradation of groundwater quality through disturbance to acid sulfate soils	Moderate
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Contamination of groundwater systems – spills and leaks	Moderate
Groundwater to Support	Moderate	Seepage of brine from RO	Moderate

Biological Areas Groundwater for consumptive or productive uses		plant	
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Impacts on groundwater dependant ecosystems	Moderate
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Excavation activities – dewatering	Low
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Vertical migration of contaminants to deeper groundwater	Moderate
Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Moderate	Plant Decommissioning	Moderate
Feed Gas Pipeline and Tunnel			
Environmental Value	**Sensitivity**	**Identified Impact**	**Assessed Magnitude**
Groundwater for consumptive or productive uses	Low	Reduced aquifer recharge	Very Low
Groundwater for consumptive or productive uses	Low	Altered aquifer characteristics	Very Low
Groundwater for consumptive or productive uses	Low	Groundwater impacts from dewatering	High
Groundwater for consumptive or productive uses	Low	Altered groundwater flow system due to tunnelling, causing saline intrusion	Moderate

Groundwater for consumptive or productive uses	Low	Degradation of groundwater quality through disturbance to acid sulfate soils	High
Groundwater for consumptive or productive uses	Low	Vertical migration of contaminants to deeper groundwater system	Moderate
Groundwater for consumptive or productive uses	Low	Contamination of groundwater systems from spills and leaks of petroleum and chemicals	Moderate
Groundwater for consumptive or productive uses	Low	Vertical migration of contaminants to deeper groundwater systems.	Moderate
Temporary Worker Accommodation Facilities and Launch Site 1			
Environmental Value	**Sensitivity**	**Identified Impact**	**Assessed Magnitude**
Groundwater to Support Biological Areas	Low	Reduced aquifer recharge	Very Low
Groundwater for consumptive or productive uses			
Groundwater to Support Biological Areas	Low	Altered aquifer characteristics	Very Low
Groundwater for consumptive or productive uses			
Groundwater to Support Biological Areas	Low	Degradation of shallow groundwater quality from leaks and spills of sanitation systems	Moderate
Groundwater for consumptive or productive uses			
Groundwater to Support Biological Areas	Low	Contamination of groundwater systems – spills and leaks	Moderate
Groundwater for consumptive or productive uses			
Groundwater to Support	Low	Degradation of groundwater	Moderate

Biological Areas		quality through disturbance to acid sulfate soils	
Groundwater for consumptive or productive uses			
Groundwater to Support Biological Areas	Low	Impact to groundwater dependant ecosystems	Moderate
Groundwater for consumptive or productive uses			
Groundwater to Support Biological Areas	Low	Vertical migration of contaminants to deeper groundwater system	Moderate
Groundwater for consumptive or productive uses			

Note 1 Sensitivity classification from Table 5.4 in section 5 Environment Values.

7 SIGNIFICANCE ASSESSMENT AND IMPACT MITIGATION

Section 6 identified potential impacts related to the project and assessed the magnitude of the impacts, should they occur. This impact assessment underpins the development of management and mitigation measures to ensure that the identified impacts are addressed, and that environmental values are not adversely or irreversibly impacted. Application of appropriate management and mitigation measures will reduce the potential for adverse ‘residual impacts’ in the study area. Residual impacts are the potential impacts remaining after the application of mitigation measures or design responses.

The extent to which potential impacts have been reduced is also determined by undertaking an assessment of the significance of the residual impacts, giving a measure of the effectiveness of the mitigation measures or design responses in reducing the magnitude of the potential impacts. If proposed mitigation measures or design responses are ineffective in reducing the significance of the residual impacts, additional or new measures/responses need to be developed.

The sensitivity of the environmental values of the groundwater systems were assessed as having either low or moderate sensitivity depending on aquifer physical conditions (Section 5). A sensitivity of moderate was adopted for the LNG plant area on Curtis Island as bedrock confined systems may occur at this site. For the remaining sites, a sensitivity of low was adopted as these areas are unlikely to impact confined bedrock systems.

This section of the report presents mitigation measures for the impacts identified in Section 6. The significance of the pre-mitigated impacts and post-mitigation is assessed using the assessed sensitivity of the environmental values (Section 5) and magnitude of impacts (Section 6).

7.1 Significance Assessment

The significance of impacts to an environmental value is determined by applying the sensitivity and magnitude ratings obtained to the assessment matrix Table 7.1. The significance of the impacts can be determined from the assessment matrix Table 7.2. This method has been used to assess the pre-mitigated and residual impacts presented later in this section.

Five categories for interpreted significance for impacts and residual impacts are provided in Table 7.2, ranging from very low through to very high.

Table 7.1: Matrix for the assessment of significance of groundwater related impact

Impact Magnitude Rating (refer Section 6)	**Sensitivity Rating** (refer Section 5)				
	Very Low	Low	Moderate	High	Very High
Very Low	1	2	3	4	5
Low	2	4	6	8	10
Moderate	3	6	9	12	15
High	4	8	12	16	20
Very High	5	10	15	20	25

Table 7.2: Impact significance: assessment interpretation

Category	**Score**	**Legend Colour**
Very Low	1-2	🟩
Low	3-4	🟩
Moderate	5-9	🟨
High	10-16	🟧
Very High	20-25	🟥

7.2 Mitigation Measures

7.2.1 Mitigation of Impacts Associated with the LNG Plant

Mitigation measures, relating to a range of potential impacts to the LNG plant, have been identified below.

Reduced aquifer recharge

The clearing of vegetation, resurfacing with impermeable materials and ground compaction during construction of the LNG plant, may reduce infiltration rates and recharge to the shallow unconfined groundwater systems, however the magnitude of impact, assuming it occurs, will be very low.

No specific mitigation is proposed to address this impact at the LNG plant as the magnitude of this potential impact, assuming it occurs, will very low.

Altered aquifer characteristics

Ground compaction during construction of the LNG plant, may change the porosity and permeability of the shallow unconfined groundwater systems, however the magnitude of impact, assuming it occurs, will be very low.

No specific mitigation is proposed to address this impact at the LNG plant as the magnitude of this potential impact, will be very low.

Degradation of groundwater quality due to disturbance to acid sulfate soils

The potential impacts of ASS are specifically addressed in the separate technical study ‘Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.

That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.

Contamination of groundwater systems – spills and leaks

The magnitude of impact, assuming it occurs, is considered to be moderate.

Measures should be implemented to reduce the likelihood of uncontained fuel, oil or chemical release entering the groundwater system. Typical measures are presented below:

- Conveyance, storage and handling of fuels, lubricants, chemicals and effluents in compliance with relevant Australian standards, especially AS1940-2004 (Australian Standards for the storage and handling of flammable and combustible liquids).
- Store all bulk chemicals in above ground storage tanks located within suitable secondary containment areas (bunded areas) constructed in accordance with Australian Standards.
- Contain all fuel or oil storage facilities within bunded areas.
- Maintain accurate records of fuel oil or chemicals stored in UST to enable leak detection through quantity auditing.
- Design the facility drainage system such that accidental releases of hazardous substances are collected to reduce the chance of contamination seeping into the groundwater system.
- Clean up leaks or spills of hazardous materials immediately in accordance with appropriate emergency clean-up procedures. This should be done to prevent possible mobilisation of contaminants into the groundwater.

In addition:

- Carry out audits of disposal facilities, disposal permits, and working conditions for compliance with regulations.
- Develop and implement an emergency spill response plan.

The potential impacts associated with waste generation and management are specifically addressed in the separate technical study ‘Arrow LNG Waste Impact Assessment’ (Coffey Environments, 2011b). That report provides the specific strategies for managing waste, including mitigation of impacts, and development of an integrated site health, safety and environmental management system (HSEMS) to provide a framework for the control, mitigation, monitoring, reporting and auditing necessary.

Seepage of brine from Reverse Osmosis (RO) plant

Potential impacts relating to storage and handling of brine water as a result of the reverse osmosis plant have been identified. The magnitude of these impacts has been assessed as moderate. Brine will be discharged from the plant to the harbour, and site storage should be minimised to reduce the potential for leakage and impact to shallow groundwater.

Impacts to groundwater dependent ecosystems

The magnitude of impacts, if they occur, is likely to be moderate.

Impacts to groundwater dependent ecosystems are associated with contaminated groundwater due to spills and leaks. These impacts are mitigated by implementing the mitigation measures for contamination of groundwater systems identified above.

Excavation activities - dewatering

The magnitude of impact, assuming it occurs, is considered to be low.

Dewatering during excavation activities may generate significant volumes of poor quality water on site and may alter groundwater flow patterns. Impacts may include saline intrusion. Excavation activities also have the potential to cause deterioration in groundwater quality due to the exposure of acid sulfate soils where they occur.

These impacts should be mitigated through:

- Managing acid sulfate soils as described in Coffey Geotechnics 2011b.
- Minimising the extent of construction dewatering required and its duration.

Any dewatering that impacts ASS horizons requires appropriate investigation and management. Dewatering for civil infrastructure may be required during the construction of the project. All dewatering events shall be managed and monitored to ensure that groundwater quality is not affected by the disturbance of ASS. The establishment of the baseline quality and management of dewatering where ASS may be encountered is covered in the separate technical study report ‘Arrow Energy LNG Project, Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b).

Vertical migration of contaminants to deeper groundwater system

The magnitude of impact, assuming it occurs, is considered to be moderate.

These impacts should be mitigated by adhering to the mitigation measures for contamination of groundwater systems, as described above.

7.2.2 Mitigation of Impacts Associated with the Feed Gas Pipeline and Tunnelling

The feed gas pipeline and associated infrastructure will be designed to high standards and will be constructed using appropriate materials and methods. The feed gas pipeline will be monitored by leak detection systems.

Sludge or other waste associated with pipeline cleaning activity is covered in the separate technical study ‘Arrow LNG Waste Impact Assessment’ (Coffey Environments, 2011b).

Reduced aquifer recharge

The clearing of vegetation, resurfacing with impermeable materials and ground compaction during construction of the Feed Gas Pipeline and Tunnelling, may reduce infiltration rates and recharge to the shallow unconfined groundwater systems, however the magnitude of impact, assuming it occurs, will be very low.

No specific mitigation is proposed to address this impact as the magnitude of this potential impact, assuming it occurs, will be very low.

Altered aquifer characteristics

Ground compaction during construction of the Feed Gas Pipeline and Tunnelling may change the porosity and permeability of the shallow unconfined groundwater systems, however the magnitude of impact, assuming it occurs, will be very low.

No specific mitigation is proposed to address this impact as the magnitude of this potential impact, will very low.

Groundwater impacts from dewatering

Aquifer dewatering may be required during trenching, excavations or tunnelling. No ongoing dewatering will be required once the tunnel is commissioned.

The magnitude of impacts from dewatering ranged from very low (alteration of permeability, porosity, and storage within the trench) to high (saline-water intrusion during dewatering activities).

The potential for saline-water intrusion (i.e. seawater) to fresh water aquifers adjacent to the coast exists during dewatering activities in the vicinity of the coast. The duration of dewatering should be minimised, and groundwater EC should be monitored along with groundwater levels near to the coast to identify if saline water intrusion to coastal aquifers is occurring. Significant increases in groundwater EC should trigger a review of dewatering activities, and controls (such as engineered or hydraulic controls) should be implemented to minimise the extent of aquifer drawdown and to avoid saline-water encroachment. Engineering controls could include sheet piling of excavations and/or groundwater reinjection.

Altered groundwater flow system due to tunnelling, causing saline intrusion

The magnitude of impact, assuming it occurs, is considered to be moderate however it is recognised that in the area of potential impact any groundwater may have little or no practical beneficial use.

These impacts will be satisfactorily mitigated by minimising the duration of construction dewatering, as ongoing operation of the completed tunnel does not require dewatering.

Degradation of groundwater quality through disturbance to acid sulfate soils

The potential impacts of ASS are specifically addressed in the separate technical study ‘Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.

Contamination of groundwater systems from spills and leaks of petroleum and chemicals

The magnitude of impact, assuming it occurs, is considered to be moderate.

Measures should be implemented to reduce the likelihood of uncontained fuel, oil or chemical release entering the groundwater system as described for the LNG plant above.

Vertical migration of contaminants to deeper groundwater system

The magnitude of impact, assuming it occurs, is considered to be moderate.

These impacts should be mitigated by implementing the measures for contamination of groundwater systems, as described above.

7.2.3 Mitigation of Impacts Associated with the TWAFs and Launch Site 1

Reduced aquifer recharge

The clearing of vegetation, resurfacing with impermeable materials and ground compaction during construction of the TWAFs and Launch Site 1, may reduce infiltration rates and recharge to the shallow unconfined groundwater systems, however the magnitude of impact, assuming it occurs, will be very low.

No specific mitigation is proposed to address this impact as the magnitude of this potential impact, assuming it occurs, will be very low.

Altered aquifer characteristics

Ground compaction during construction of the TWAFs and Launch Site 1 may change the porosity and permeability of the shallow unconfined groundwater systems, however the magnitude of impact, assuming it occurs, will be very low.

No specific mitigation is proposed to address this potential impact at the TWAFs and Launch Site 1 as the magnitude of this impact, will be very low.

Degradation of shallow groundwater quality from leaks and spills of sanitation systems

At the TWAF sites the magnitude of this impact will be low. At Launch Site 1 a longer operational duration would increase the magnitude of an impact to moderate.

Sanitation systems will be installed and maintained to minimise leakage of effluent.

Systems will be connected to sewers where locally present. Where sewers are not present, wastewater will be collected and transported offsite to a licensed disposal facility.

Contamination of groundwater systems from spills and leaks of petroleum and chemicals

At the TWAF sites, the duration of site use is short, and assuming the impact occurs the magnitude of impact is likely to be moderate. At Launch Site 1 the more limited laydown area site operation indicates the magnitude of impact may be low.

To reduce the likelihood of uncontained releases of fuel, oil or chemical entering the groundwater system, the following recommendations are made:

- Conveyance, storage and handling of fuels, lubricants, chemicals and effluents in compliance with relevant Australian standards, especially AS1940-2004 (Australian Standards for the storage and handling of flammable and combustible liquids).
- Design the facility drainage system such that accidental releases of hazardous substances are collected to reduce the chance of contamination seeping into the groundwater system.

- Develop and implement an emergency spill response plan and procedures.
- Maintain accurate records of fuel, oil or chemical volumes purchased and stored on-site to allow regular quantity auditing.

A monitoring plan will be developed as specified in Section 8.

Degradation of groundwater quality through disturbance to acid sulfate soils

The potential impacts of ASS are specifically addressed in the separate technical study ‘Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.

Impact to groundwater dependent ecosystems

Impacts to groundwater dependent ecosystems are associated with contaminated groundwater due to spills and leaks and the magnitude of impact, assuming it occurs, is considered to be moderate.

These impacts should be mitigated by adhering to the mitigation measures for contamination of groundwater systems above.

Vertical migration of contaminants to deeper groundwater system

The magnitude of impact, assuming it occurs, is considered to be moderate.

These impacts should be mitigated by adhering to the to the mitigation measures for contamination of groundwater systems, as described above.

7.2.4 Mitigation of Impacts Associated with Decommissioning

The magnitude of impacts assuming the presence of hazardous materials onsite without adequate management is considered to be moderate.

A materials handling and waste management plan should be prepared to manage any potential contaminants, soils or materials that might result in impacts to shallow groundwater through either short-term or long-term leaching. This plan will need to be prepared prior to commencement of decommissioning activities.

The decommissioning of all monitoring bores will follow standard guidelines including the Manual of Water Well Construction Practices (National Water Well Association, 1977) and Minimum Construction Requirements for Water Bores in Australia (National Minimum Bore Specifications Committee, 2003).

7.3 Residual Impacts

The residual impacts associated with the construction, operation and decommissioning of the project are presented in Tables 7.3a to 7.3c. Each of the residual impacts is assessed for significance after the implementation of the mitigation measures identified in Section 7.

The mitigated residual impact significance for the LNG plant site on Curtis Island ranged from low to moderate indicating that the project development is unlikely to impact the Island groundwater environment adversely when operated in accordance with the mitigation measures proposed.

The residual impact significance for the mainland sites all ranged from low to very low indicating that the project development is unlikely to impact the mainland groundwater environment adversely when operated in accordance with the mitigation measures proposed.

Table 7.3a: Impact significance – LNG Plant

Impact	Potential Values Impacted	Unmitigated Impact Significance			Summary of Mitigation Measures	Residual (Mitigated) Impact Significance	
		Sensitivity*	Magnitude	Significance Ranking		Magnitude	Significance Ranking
Reduced aquifer recharge	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Moderate**	**Very Low**	**Low (3)**	No mitigation required.	**Very Low**	**Low (3)**
Altered aquifer characteristics	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Moderate**	**Very Low**	**Low (3)**	No mitigation required.	**Very Low**	**Low (3)**
Degraded of groundwater quality through disturbance to ASS	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Moderate**	**Moderate**	**Moderate (9)**	The potential impacts of ASS are specifically addressed in the separate technical study 'Acid Sulfate Soil Impact Assessment' (Coffey Geotechnics, 2011b).	**Low**	**Moderate (6)**
Contamination of groundwater systems – spills and	Groundwater to Support Biological Areas Groundwater for	**Moderate**	**Moderate**	**Moderate (9)**	Convey, store and handle hazardous fuels, lubricants, chemicals and effluents in compliance with relevant Australian standards, especially AS1940-2004 (Australian Standards for the storage	**Low**	**Moderate (6)**

leaks	consumptive or productive uses				and handling of flammable and combustible liquids). Store all bulk chemicals in above ground storage tanks located within suitable secondary containment areas (bunded areas). Contain all fuel or oil storage facilities within bunded areas Maintain accurate records of fuel, oil or chemical volumes purchased and stored on-site to allow regular quantity auditing. Design the facility drainage system such that accidental releases of hazardous substances are collected to reduce the chance of contamination seeping into the groundwater system. Clean up leaks or spills of hazardous materials immediately accordingly to appropriate emergency clean-up operations. Carry out audits of disposal facilities, disposal permits, and working conditions for compliance with regulations. Develop and implement an emergency spill response plan. Address mitigation measures in the design phase.		
Seepage of brine from RO	Groundwater to Support Biological	**Moderate**	**Moderate**	**Moderate (9)**	Brine will be discharged from the plant to the harbour, and site storage should	**Very Low**	**Low (3)**

plant	Areas Groundwater for consumptive or productive uses				be minimised to reduce the potential for leakage and impact to shallow groundwater.		
Impacts to groundwater dependant ecosystems	Groundwater to Support Biological Areas	**Moderate**	**Moderate**	**Moderate (9)**	Measures as for contamination of groundwater systems as described above.	**Low**	**Moderate (6)**
Excavation activities – dewatering	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Moderate**	**Low**	**Moderate (6)**	Minimise construction dewatering and duration. Manage Acid sulfate impacts per Coffey Geotechnics 2011b.	**Very Low**	**Low (3)**
Vertical migration of contaminants to deeper groundwater	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Moderate**	**Moderate**	**Moderate (9)**	Measures for contamination of groundwater systems, as described above.	**Very Low**	**Low (3)**
Plant Decommissioning	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Moderate**	**Moderate**	**Moderate (9)**	Materials handling and waste management plan to manage any potential contaminants, soils or materials that might result in impacts to shallow groundwater through either short-term or long-term leaching. Prepare prior to commencement of decommissioning activities. Decommissioning of all monitoring bores	**Very Low**	**Low (3)**

					to follow standard guidelines including the Manual of Water Well Construction Practices (National Water Well Association, 1977) and Minimum Construction Requirements for Water Bores in Australia (National Minimum Bore Specifications Committee, 2003).		

Table 7.3b: Impact significance – Feed Gas Pipeline and Tunnel

Impact	**Potential Values Impacted**	**Unmitigated Impact Significance**			**Summary of Mitigation Measures**	**Residual (Mitigated) Impact Significance**	
		Sensitivity*	**Magnitude**	**Significance Ranking**		**Magnitude**	**Significance Ranking**
Reduced aquifer recharge	Groundwater for consumptive or productive uses	**Low**	**Very Low**	**Very Low (2)**	No mitigation required.	**Very Low**	**Very Low (2)**
Altered aquifer characteristics	Groundwater for consumptive or productive uses	**Low**	**Very Low**	**Very Low (2)**	No mitigation required.	**Very Low**	**Very Low (2)**
Groundwater impacts from dewatering	Groundwater for consumptive or productive uses	**Low**	**High**	**Moderate (8)**	Minimise dewatering duration. Further investigation and engineering controls implemented if monitoring programs identify/trigger potential risks.	**Low**	**Low (4)**
Altered groundwater flow system due to tunnelling, causing saline	Groundwater for consumptive or productive uses	**Low**	**Moderate**	**Moderate (6)**	Minimise duration of dewatering. The magnitude of impact, assuming it occurs, is considered to be moderate These impacts will be satisfactorily mitigated by minimising the duration of construction dewatering, as ongoing operation of the completed tunnel does not	**Low**	**Low (4)**

intrusion					require dewatering.		
Degraded groundwater quality through disturbance to ASS	Groundwater for consumptive or productive uses	**Low**	**High**	**Moderate (8)**	The potential impacts of ASS are specifically addressed in the separate technical study 'Acid Sulfate Soil Impact Assessment' (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts.	**Low**	**Low (4)**
Contamination of groundwater systems from spills and leaks of petroleum and chemicals	Groundwater for consumptive or productive uses	**Low**	**Moderate**	**Moderate (6)**	Measures should be implemented to reduce the likelihood of uncontained fuel, oil or chemical release entering the groundwater system as described for the LNG plant above.	**Low**	**Low (4)**
Vertical migration of contaminants to deeper groundwater system	Groundwater for consumptive or productive uses	**Low**	**Moderate**	**Moderate (6)**	Measures for contamination of groundwater systems, as described above.	**Very Low**	**Very Low (2)**

Table 7.3c: Impact significance – Temporary Worker Accommodation Facilities and Launch Site 1

Impact	**Potential Values Impacted**	**Unmitigated Impact Significance**			**Summary of Mitigation Measures**	**Residual (Mitigated) Impact Significance**	
		Sensitivity*	**Magnitude**	**Significance Ranking**		**Magnitude**	**Significance Ranking**
Reduced aquifer recharge	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Low**	**Very Low**	**Very Low (2)**	No mitigation required.	**Very Low**	**Very Low (2)**
Altered aquifer characteristics	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Low**	**Very Low**	**Very Low (2)**	No mitigation required.	**Very Low**	**Very Low (2)**
Degraded shallow groundwater quality from leaks and spills of sanitation systems	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Low**	**Moderate**	**Moderate (6)**	Install and maintain sanitation systems to minimise leakage of effluent. Connect systems to sewers where locally present or install on site systems to Australian Standards.	**Low**	**Low (4)**
Contamination of	Groundwater to Support	**Low**	**Moderate**	**Moderate (6)**	The following recommendations	**Low**	**Low (4)**

groundwater systems from spills and leaks of petroleum and chemicals	Biological Areas Groundwater for consumptive or productive uses				are made: • Conveyance, storage and handling of fuels, lubricants, chemicals and effluents in compliance with relevant Australian standards, especially AS1940-2004 (Australian Standards for the storage and handling of flammable and combustible liquids). • Design the facility drainage system such that accidental releases of hazardous substances are collected to reduce the chance of contamination seeping into the groundwater system. • Develop and implement an emergency spill response plan and procedures. • Clean up leaks/spills of hazardous materials according to emergency spill response plan. • Maintain accurate records of fuel, oil or chemical volumes purchased and stored on-site to allow regular quantity auditing.		

Degradation of groundwater quality through disturbance to ASS	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Low**	**Moderate**	**Moderate (6)**	The potential impacts of ASS are specifically addressed in the separate technical study 'Acid Sulfate Soil Impact Assessment' (Coffey Geotechnics, 2011b). That report provides strategies for managing impacts, including development of an ASS Management Plan (ASSMP) to address ASS impacts.	**Low**	**Low (4)**
Impact to groundwater dependant ecosystems	Groundwater to Support Biological Areas	**Low**	**Moderate**	**Moderate (6)**	Measures for contamination of groundwater systems, as described above.	**Low**	**Low (4)**
Vertical migration of contaminants to deeper groundwater system	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	**Low**	**Moderate**	**Moderate (6)**	Measures for contamination of groundwater systems, as described above.	**Very Low**	**Very Low (2)**

***** Sensitivity classification from Table 5.4 in section 5 Environment Values.

8 INSPECTION AND GROUNDWATER MONITORING

Arrow Energy is committed to understanding, managing and mitigating the potential impacts of their LNG plant operations on the environmental values of groundwater systems. The impact and significance assessment allowed mitigation measures to be identified to reduce the impacts of the project on groundwater systems. Environment protection measures have been identified to assess the effectiveness of mitigation measures. These measures are underpinned by groundwater baseline assessment and monitoring. Management decisions and an adaptive approach to site development will also be informed by the results of the monitoring program.

8.1 Inspections

Regular inspections should be carried out to verify and check that the control, mitigation and management measures proposed in Section 7 are being implemented. Inspections should include the following:

- Regular inspection of the handling, storage and disposal of fuels and petroleum products at project sites for compliance with relevant Australian standards, especially AS1940-2004 (Australian Standards for the storage and handling of flammable and combustible liquids).
- Regular inspection of the handling, storage and disposal of chemicals at project sites for compliance with relevant Australian standards.
- Regular inspection of the implementation of the acid sulfate soil management strategies in accordance with the Acid Sulfate Soils Management Plan to be developed in accordance with the requirements of the Acid Sulfate Soils Impact Assessment report (Coffey Geotechnics, 2011b).
- Regular inspection of the feed gas pipeline and associated infrastructure through physical inspection, proprietary instrumentation, and internal inspection devices and equipments such as leak detection system, corrosion monitoring, fluid quality monitoring, and remote intrusion monitoring systems in accordance with the Australian Standard Pipelines-Gas and Liquid Petroleum (operation and maintenance) AS2885.3.
- Regular inspection of groundwater monitoring wells, including replacement of any wells required as part of the groundwater monitoring (described below) that have been damaged or destroyed.

In addition to the above inspections, further groundwater investigations are required as documented in the separate technical study report ‘Preliminary Site Investigation Contaminated Land Report Arrow Energy LNG Plant’ (Coffey Geotechnics, 2011d).

8.2 Groundwater Monitoring

8.2.1 Environment Protection Measures and Monitoring Objectives

The implementation of environment protection measures is necessary to assess the impacts of the project on associated environmental values and groundwater quality and quantity. A robust groundwater baseline assessment and groundwater monitoring program will underpin these measures and will provide a more informed understanding of baseline conditions against which potential impacts can be assessed.

The objectives of the groundwater monitoring program are to:

- Provide a configuration of wells that allows changes in groundwater levels and conditions to be identified across the project study area and within key aquifers.
- Monitoring parameters that are indicators of risk to environment values.
- Gain further understanding of aquifer interactions and verify the understanding of regional hydrogeology.
- Identify long-term groundwater level trends and potential cumulative effects to environment values from current and future development.
- Provide information to differentiate effects between the operating plant and other sources of groundwater variability.
- Develop an "early warning system" that identifies areas where environment values are potentially impacted by project activities.
- Share information with regulatory authorities, key stakeholders and the community.

Monitoring of groundwater levels and groundwater quality should be carried out by an environmental scientist or a hydrogeologist and follow guidelines and standards including EPA Guidelines (June 2007) for Regulatory Monitoring and Testing – Groundwater Sampling, Australian Standards AS/NZS 5667.1:1998 (Water quality sampling - Guidance on Design of Sampling Programs, Sampling Techniques, the Preservation and Handling of Samples), AS/NZS 5667.11: Water quality sampling – Guidance on sampling of groundwater).

Quality assurance and quality control of sampling programs should be in accord with the requirements of Schedule (B) 2 in the National Environment Protection Measure (NEPM, 1999).

8.2.2 Groundwater Monitoring Activities

Baseline and impact monitoring are proposed based on the outcomes of the significance assessment. Table 8.1 summarises the field and laboratory parameters and proposed sampling frequency for both baseline and impact monitoring.

Baseline Monitoring and Bore Network

It is recommended that the bore inventory assessment from the DERM database is used as a basis for gathering and compiling additional baseline groundwater data (i.e. groundwater conditions existing prior to construction). It is important that this snapshot of groundwater information is compiled prior to the commissioning of the LNG plant. A suitable monitoring network will need to be established prior to monitoring including existing and/or new monitoring wells.

The monitoring of groundwater levels and groundwater chemistry at existing bores BH2, BH12, BH16, BH17, BH21, and BH35 prior to construction to obtain baseline data is also recommended. These bores are located on Curtis Island in areas of potential high disturbance from project activities. It is likely that many or all of these wells could be destroyed or compromised during plant construction. New monitoring sites will need to be installed to replace existing monitoring sites if they are destroyed or damaged during construction. Specific locations for these and additional wells as required to satisfactorily monitor the groundwater system will need to be established post-construction at the site commissioning phase.

Impact Monitoring

The implementation of a groundwater monitoring program that includes a representative suite of bores in the shallow and deeper groundwater systems is recommended.

The monitoring program will provide water levels and water quality data of the aquifers within the potentially impacted areas. In particular, it is recommended to implement groundwater monitoring programs around the TWAF and Launch Site 1 sites. Monitoring wells should be focused on activities/infrastructure that has the potential to impact groundwater systems (i.e. sanitation, fuelling or maintenance facilities).

Monitoring reports summarising the results for specified periods should be prepared and kept on file for inspection or for reporting upon request by authorities. The reports should include all monitoring data that has been collected and all management measures that have been carried out in the study area. The groundwater monitoring reports should include the following:

- Time and date of measurements and sampling events;
- Weather conditions;
- Groundwater levels;
- Groundwater quality field measurements;
- Results of laboratory analysis for groundwater samples; and
- Summary of the changes of groundwater levels and water quality during the monitored period. The groundwater monitoring programme will be reviewed after 3 years with any changes and ongoing requirements agreed with the relevant authority.

Table 8.1: Field and laboratory parameters and sampling frequency for baseline and impact monitoring

Activity	Frequency	Monitoring Bores	Parameters
Baseline Monitoring			
Level Monitoring	Monthly	A representative selection of available bores on the mainland and Curtis Island	Groundwater level measurement.
Field Parameters	Monthly	A representative selection of available bores on the mainland and Curtis Island	pH, electrical conductivity, temperature, dissolved oxygen, redox potential (Eh).
Laboratory Analytes	Once pre-construction	A representative selection of available bores on the mainland and Curtis Island	TDS, pH, total acidity, total alkalinity Major cations (calcium, magnesium, sodium, potassium) and major anions (chloride, sulfate, bicarbonate). Total metals and dissolved metals (arsenic, cadmium, chromium, copper, nickel, lead, zinc, aluminium, manganese, selenium, iron, mercury). Ferrous Iron: Filtered and unfiltered. Nutrients: Total nitrogen, nitrate, TKN, reactive phosphorous, total phosphorus. Total petroleum hydrocarbons. Volatile

			organic compounds (VOCs).
Impact Monitoring (to start at project construction commencement)			
Level Monitoring	Quarterly	A representative selection of available bores on the mainland and Curtis Island and newly installed targeted monitoring bores	Groundwater level measurement
Field Parameters	Quarterly	A representative selection of available bores on the mainland and Curtis Island and newly installed targeted monitoring bores	pH, electrical conductivity, temperature, dissolved oxygen, redox potential (Eh).
Laboratory Analytes	Annually	A representative selection of available bores on the mainland and Curtis Island and newly installed targeted monitoring bores	TDS, pH, total acidity, total alkalinity. Major cations (calcium, magnesium, sodium, potassium) and major anions (chloride, sulfate, bicarbonate). Total metals and dissolved metals (arsenic, cadmium, chromium, copper, nickel, lead, zinc, aluminium, manganese, selenium, iron, mercury). Total petroleum hydrocarbons. VOCs. Ferrous Iron: Filtered and unfiltered. Nutrients: Total nitrogen, nitrate, TKN, reactive phosphorous, total phosphorus.

8.2.3 Dewatering Discharge from an Acid Sulfate Soil Landscape

The drainage water from the spoil disposal near the tunnel launch site, and dewatering of ASS are addressed in the separate technical study ‘Acid Sulfate Soil Impact Assessment’ (Coffey Geotechnics, 2011b). Monitoring requirements are covered under the Queensland State Planning Policy for planning and managing developments involving acid sulfate soils (Coffey Geotechnics, 2011b).

That report provides strategies for managing impacts, including development of an Acid Sulfate Soils Management Plan (ASSMP) to address ASS impacts and which will address monitoring requirements.

9 CUMULATIVE IMPACTS

This section addresses the cumulative impacts from the project, taking into consideration the effects of other known, existing and proposed projects for which groundwater related information has been provided by the Department of Infrastructure and Planning or is publicly available.

The criteria for selecting the projects for inclusion in the cumulative impact assessment are:

1. The project is located within the Gladstone region.
2. The project is being assessed by one or more of the following:
   - The State Development and Public Works Organisation Act 1971 (Qld) and has been declared by the Coordinator General as a ‘project of state significance’ for which the status of the EIS is either complete or, as a minimum, has an Initial Advice Statement published on the Department of Infrastructure and Planning (DIP) website;
   - The Environmental Protection Act 1994 (Queensland) and has completed an EIS or has an Initial Advice Statement (or similar) listed on the Department of Environment and Resource Management (DERM) website;
3. Envisaged in statutory planning documentation.

The projects that are currently proposed adjacent to the study area or in the same region include the following:

- Australia Pacific Liquefied Natural Gas Project (APLNG).
- Western Basin Strategic Dredging and Disposal Project.
- Fishermans Landing Northern Expansion Project.
- Arrow Surat Pipeline Project (formerly Surat Gladstone Pipeline Project).
- Central Queensland Pipeline Project.
- Wiggins Island Coal Terminal Project.
- Gladstone Nickel Project.
- Gladstone Steel Plant Project.
- Moura Link-Aldoga Rail Project.
- Gladstone-Fitzroy Pipeline Project.
- Hummock Hill Island Community Project.
- Boyne Island Aluminium Smelter Extension of Reduction Lines Project.
- Gladstone LNG Project (GLNG)(Fishermans Landing).
- Queensland Curtis Liquified Natural Gas Project (QCLNG).
- Yarwun Alumina Refinery Expansion Project.

Available groundwater related information on the above projects was reviewed to determine the nature and extent of potential impacts as relevant to the environmental values of groundwater of the Gladstone region. A qualitative approach was used to identify the cumulative impacts from other projects with the Arrow LNG plant.

Potential groundwater impacts in relation to other projects were identified. These include:

- Reduced infiltration rates and recharge to the groundwater system;
- Compaction of the underlying unconfined shallow aquifers, thereby potentially altering the hydrogeological characteristics (i.e. porosity, permeability, structure). This may affect the groundwater flow, levels and gradients; and,
- Degradation of groundwater quality and adverse impact on groundwater-dependent ecosystems through release of contaminants (spills and leaks of fuels, chemicals and wastes).

Table 9.1 details the projects considered in the cumulative impact assessment and the potential cumulative impacts of these projects on groundwater resources in the study area.

Table 9.1: Groundwater cumulative impact assessment

Other projects	Potential impact[1]
Australia Pacific Liquefied Natural Gas Australia Pacific LNG Ltd ConocoPhillips and Origin Energy) (ref: APLNG, 2010)	(Located on Curtis Island) Contamination from spills and leakages. Reduced recharge due to reduced infiltration capacity. Alteration to aquifer properties due to ground compaction. Impacts to groundwater dependent ecosystems.
Central Queensland Gas Pipeline AGL/Arrow Energy (ref: Queensland Government, 2007)	Contamination from spills and leakages; increased alteration of shallow hydrogeological units from construction activities and dewatering where the pipeline intersect the shallow groundwater.
Gladstone Liquefied Natural Gas Santos Limited and PETRONAS (ref: Santos Ltd and Petronas, 2009)	(Located on Curtis Island) Contamination from spills and leakages. Reduced recharge due to reduced infiltration capacity. Alteration to aquifer properties due to ground compaction. Impacts to groundwater dependent ecosystems.

Other projects	Potential impact[1]
Queensland Curtis Liquefied Natural Gas Queensland Gas Company Ltd (ref: Qld Curtis LNG, 2009)	(Located on Curtis Island) Contamination from spills and leakages. Reduced recharge due to reduced infiltration capacity. Alteration to aquifer properties due to ground compaction. Impacts to groundwater dependent ecosystems.
Port of Gladstone Western Basin Dredging and Disposal Gladstone Ports Corporation Limited (ref: Gladstone Ports Corporation, 2009b)	Increased alterations to natural groundwater levels (post development); additional contaminant sources (fuel, spills) from construction activities.
Gladstone Pacific Nickel Refinery Gladstone Pacific Nickel Limited (ref: Gladstone Pacific Nickel Limited, 2007)	Contaminant sources, including metals, solvents and fuels.
Boyne Island Aluminium Smelter Extension of Reduction Lines (ref: Queensland Government, 2007)	No contribution to cumulative impacts on groundwater as this smelter is located sufficiently far away.
Gladstone Steel Making Facility Boulder Steel Limited (ref: Boulder Steel Limited, 2008)	Contaminant sources, including metals, solvents and fuels
Arrow Surat Pipeline Surat to Gladstone Pipeline Surat Gladstone Pipeline Pty Ltd (Arrow Energy Ltd) (ref: Arrow Energy, 2009)	No contribution to cumulative impacts on groundwater as this project is located sufficiently far away from the LNG plant site.
Fisherman's Landing Port Expansion Gladstone Ports Corporation (ref: Gladstone Ports Corporation, 2009)	Contaminant sources due to spills or leaks.
Yarwun Alumina Refinery and RSF Expansion Rio Tinto (ref: WWW.Comalco.com)	Contaminant sources due to spills or leaks.
Aldoga Rail Siding and Freight terminal	Disturbances to groundwater resources due to the water

Other projects	Potential impact[1]
DIP/Queensland Rail (ref: Queensland Rail, 2009)	extraction during the construction, excavation activities (construction of rail maintenance yard and rail corridor, construction of bridges); contamination from spills or leaks.
Wiggins Island Coal Export Terminal Wiggins Island Coal Export Terminal P/L (ref: Central Queensland Ports Authority and Queensland Rail, 2006)	Contamination from spills or leaks.

Note 1 Potential groundwater impact when environmental management plans not in place and mitigation measures are not undertaken

9.1 Projects of Cumulative Impact Relevance

Projects likely to have the potential for cumulative impact to groundwater include those having similar residual impacts to the Arrow LNG Plant and being located within a spatially relevant area. The onshore activities of the Arrow LNG Plant have already been assessed as having very low potential for ongoing residual impact and are considered a low risk from a cumulative perspective. The main cumulative risk is considered from the Curtis Island development where similar LNG operations are under development.

Based on this, of the projects identified in Table 9.1 the following are considered relevant from a cumulative impact assessment of groundwater:

- **Australia Pacific Liquefied Natural Gas**
- **Gladstone Liquefied Natural Gas**
- **Queensland Curtis Liquefied Natural Gas**

Because of the similarity of these projects (ie development of LNG production facilities) the indicative mitigated residual impacts can reasonably be considered as similar. Based on the impact and mitigation assessment for the Arrow LNG plant (Section 7 of this report) these would include those impacts shown in Table 9.2.

Table 9.2: Residual impacts associated with Curtis Island LNG facilities

Impact	Potential Values Impacted	Magnitude of Mitigated Impact	Residual Significance
Reduced aquifer recharge	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Very Low	Low
Altered aquifer characteristics	Groundwater to Support Biological Areas	Very Low	Low

	Groundwater for consumptive or productive uses		
Degradation of groundwater quality through disturbance to acid sulfate soils	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses.	Low	Moderate
Contamination of groundwater systems – spills and leaks	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Low	Moderate
Seepage of brine from Reverse Osmosis (RO) plant	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Very Low	Low
Impacts to groundwater dependant ecosystems	Groundwater to Support Biological Areas	Low	Moderate
Excavation activities – dewatering	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Very Low	Low
Vertical migration of contaminants to deeper groundwater	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Very Low	Low
Plant Decommissioning	Groundwater to Support Biological Areas Groundwater for consumptive or productive uses	Very Low	Low

For cumulative groundwater impacts to arise from the construction, operation and decommissioning of these projects, such impacts must necessarily have a sufficient spatial impact to result in an overlap of impacted areas. However because the mitigated impacts identified are 1) low to moderate and 2) of limited areal extent, then it is concluded that the residual cumulative impacts will not be greater than as individually assessed.

Accordingly it is concluded that significant residual impacts are not indicated to occur to groundwater environmental values at the Arrow LNG site, and that the Arrow LNG plant construction and operation will not contribute to the cumulative residual impacts of the other relevant major projects identified.

Adherence by Arrow to the mitigation measures identified for the Arrow LNG plant will satisfactorily mitigate the potential for cumulative impacts to occur.

10 CONCLUSION

An environmental impact assessment was conducted for the planned Arrow LNG project in accordance with the Terms of Reference.

The study found that shallow groundwater resources exist at all areas potentially impacted by the project footprint. Groundwater quality is generally poor and yields are low, and accordingly groundwater resources are not well developed in the study area.

The study identified the project activities having potential to impact the groundwater environment and proposed measures for impact mitigation. Each of the residual impacts is assessed for significance after the implementation of the mitigation measures. The residual impact significance for the mainland sites all ranged from very low to low indicating that the project development is unlikely to impact the mainland groundwater environment adversely when operated in accordance with the design and mitigation measures proposed.

The mitigated residual impact significance for the LNG plant site on Curtis Island ranged from low to moderate indicating that the project development is unlikely to impact the Island groundwater environment adversely when operated in accordance with the design and mitigation measures proposed.

For cumulative groundwater impacts to arise from the construction, operation and decommissioning of these projects, such impacts must necessarily have a sufficient spatial impact to result in an overlap of impacted areas. However because the mitigated impacts identified for the LNG plant at Curtis Island are 1) low to moderate and 2) of limited areal extent, then it is concluded that the residual cumulative impacts must also be no greater than as individually assessed.

It is concluded that significant residual impacts are not indicated to occur to groundwater environmental values at the Arrow LNG plant site, and that the Arrow LNG plant development and operation will not contribute to the cumulative residual impacts of the other relevant major projects identified.

Adherence by Arrow to the mitigation measures identified for the Arrow LNG plant will satisfactorily mitigate the potential for cumulative impacts to occur.

An inspection and groundwater monitoring program has been described to include baseline monitoring and sampling, and ongoing monitoring following plant commissioning.

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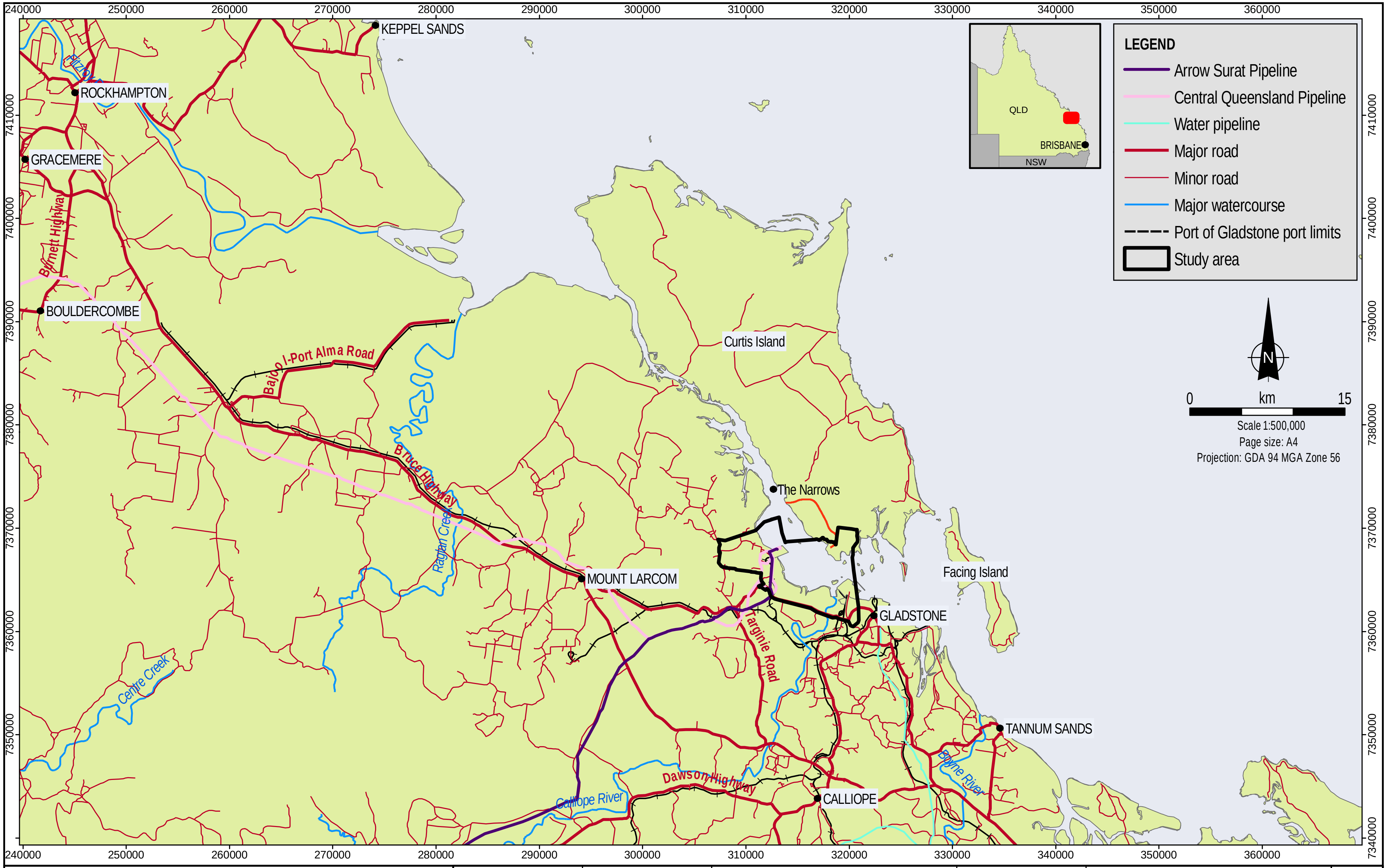
Figures



Source:
Place names, roads, railways, watercourses and pipelines from
GEODATA250k (Optimum scale 1:250,000)
Coastline from GBRMPA.
Port of Gladstone port limits digitised by Coffey Environments.

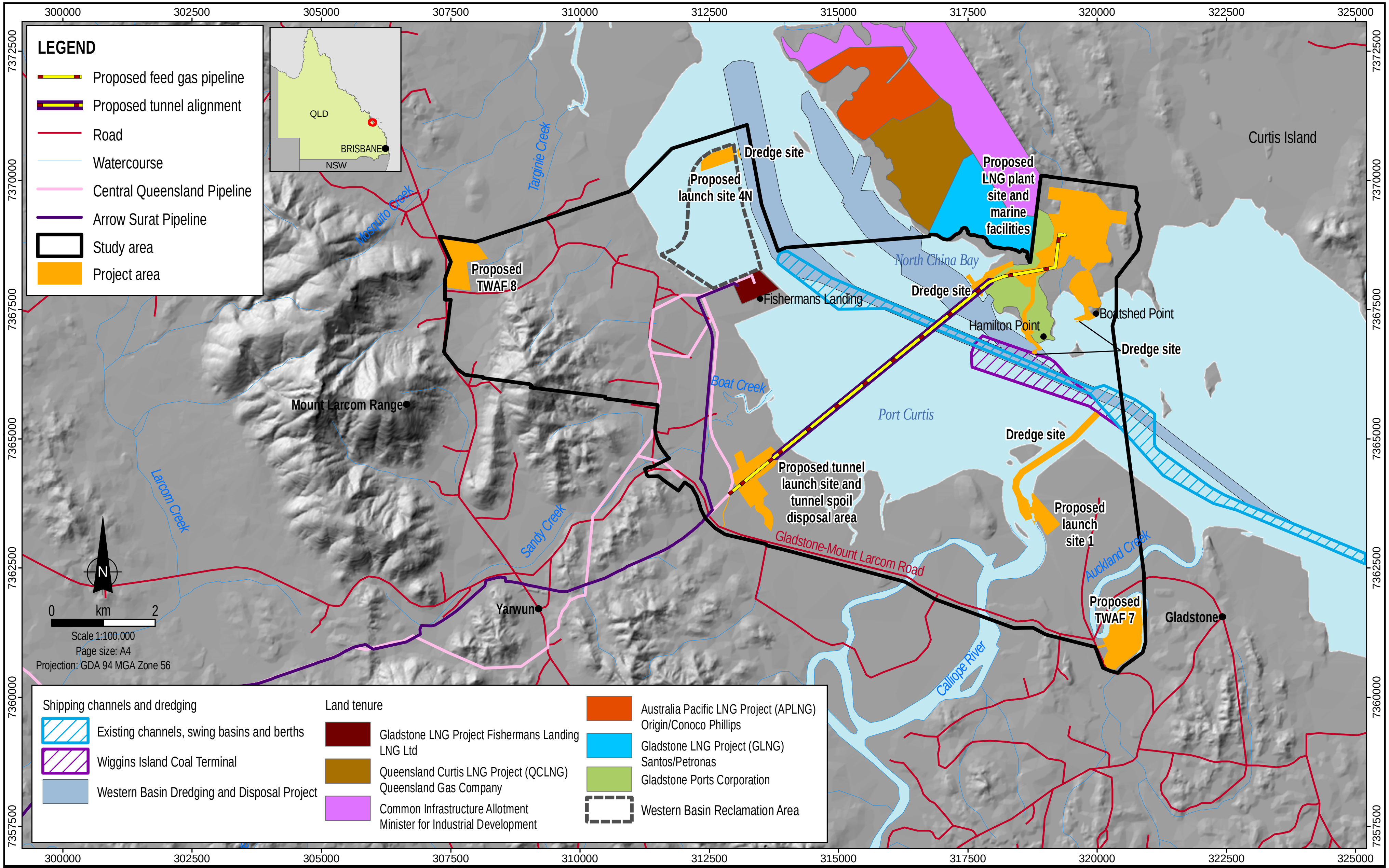
Date:
24.10.2011
MXD:
7033CA_GW2_GIS010_v0_3
File Name:
7033CA_GW2_F01.1_GIS

Arrow Energy

Arrow LNG Plant

Arrow LNG plant and regional location

Figure No:
1.1



Source:
Place names, roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Proposed feed gas pipeline, proponents and DEM from Coffey Environments.
Western Basin Dredging Master Plan from Gladstone Ports Corporation.

coffey environments

Date: 08.07.2011
MXD: 7033CA_GW2_GIS008_v0_1
File Name: 7033CA_GW2_F01.2_GIS

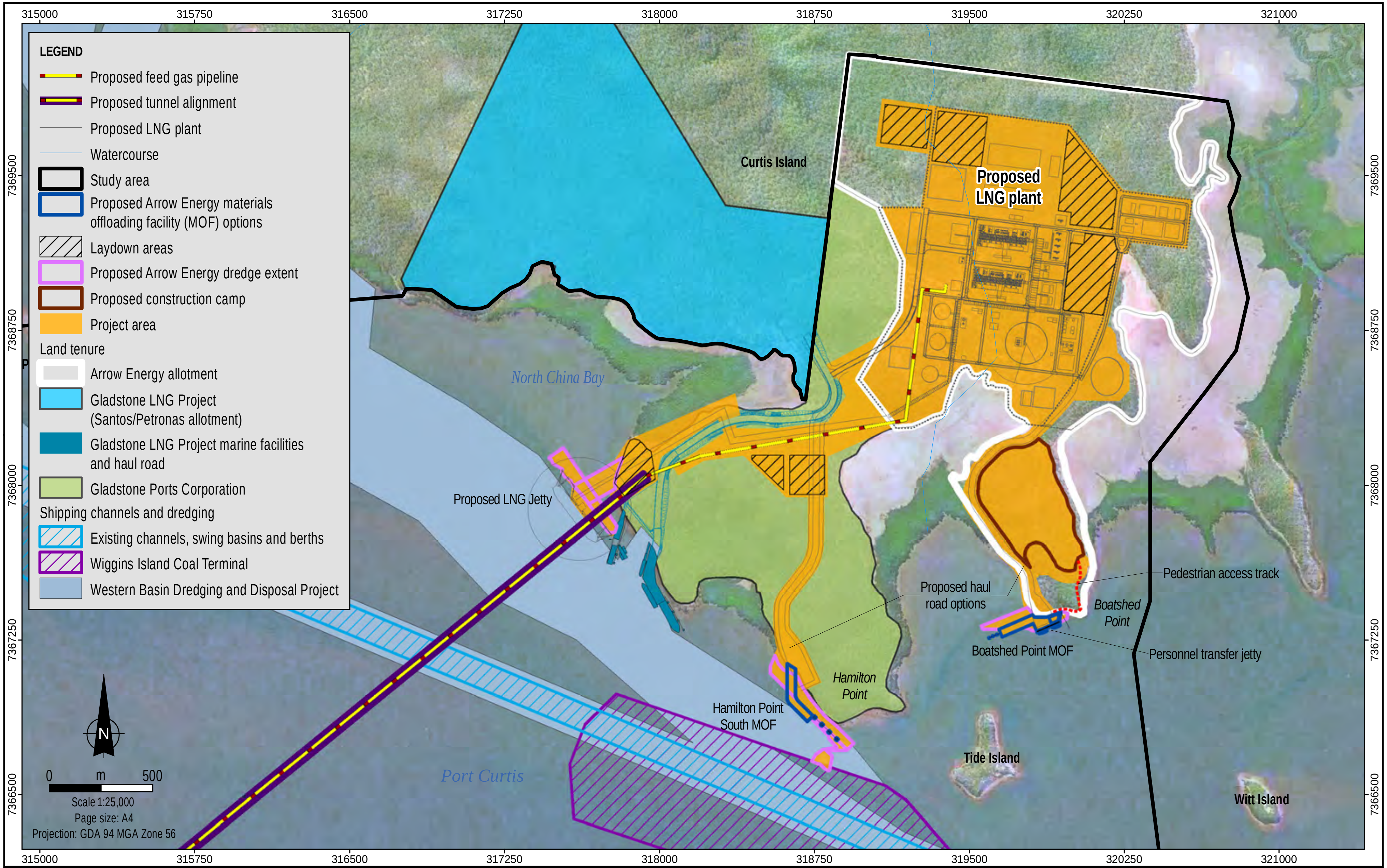
Arrow Energy

Arrow LNG Plant

arrow energy go further

Site locality and other project sites

Figure No: **1.2**



Source:
Place names, roads and watercourses from DME.
Study area, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Western Basin Dredging Master Plan and Disposal Project from Gladstone Ports Corporation.
Study area and proposed feed gas pipeline from Coffey Environments. Imagery from SPOT (2004-2007).

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Date:
08.07.2011
MXD:
7033CA_GW2_GIS009_v0_1
File Name:
7033BC_GW2_F01.3_GIS

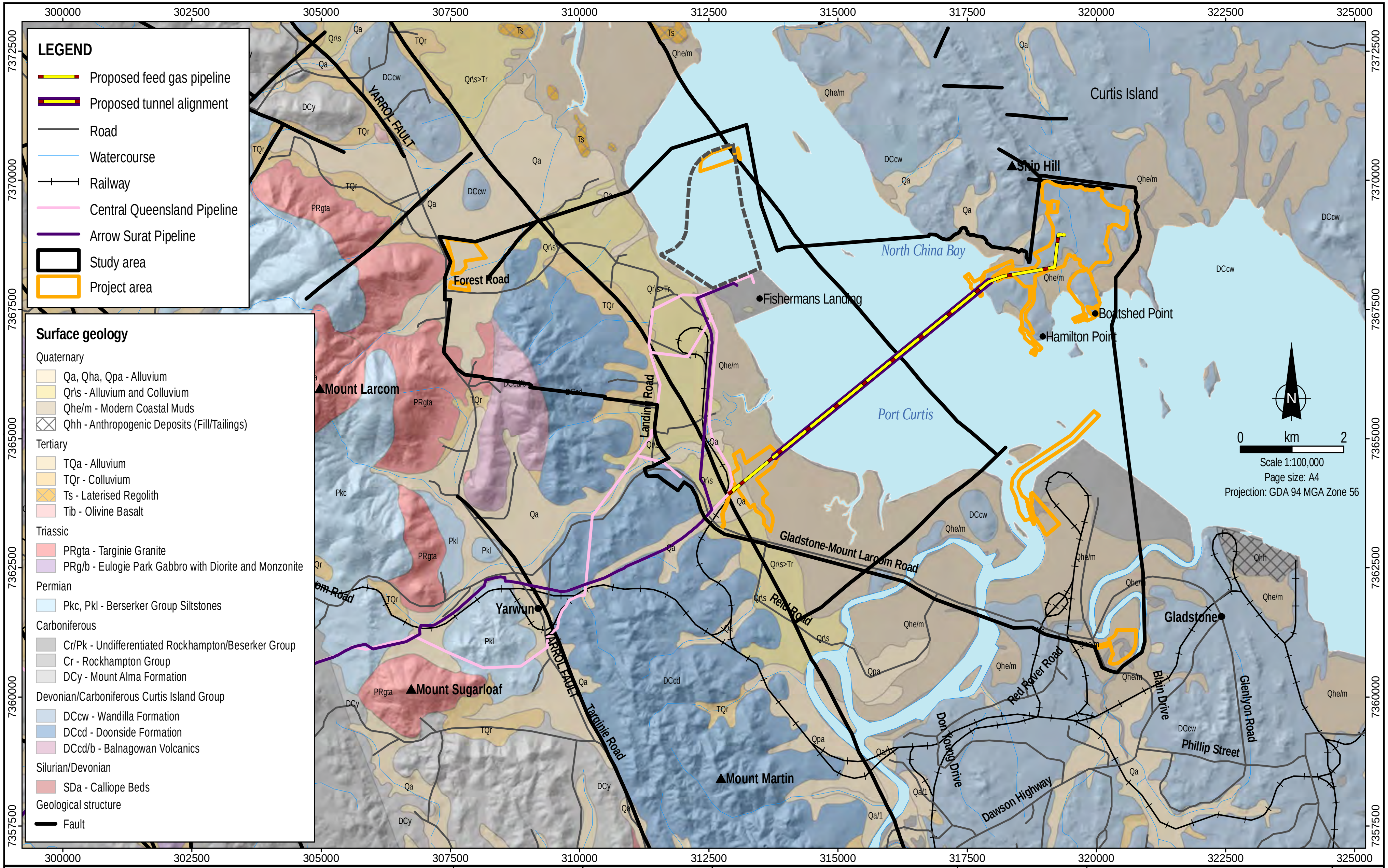
Arrow Energy

Arrow LNG Plant

arrow energy go further

Arrow LNG plant and associated infrastructure

Figure No:
1.3



Source:
Place names, roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Project area, proposed feed gas pipeline and DEM from Coffey Environments.
Surface geology and structure from DME 1:100,000 digital geological mapping.

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Date: 24.10.2011
MXD: 7033CA_GW2_GIS012_v0_1
File Name: 7033CA_GW2_F04.1a_GIS

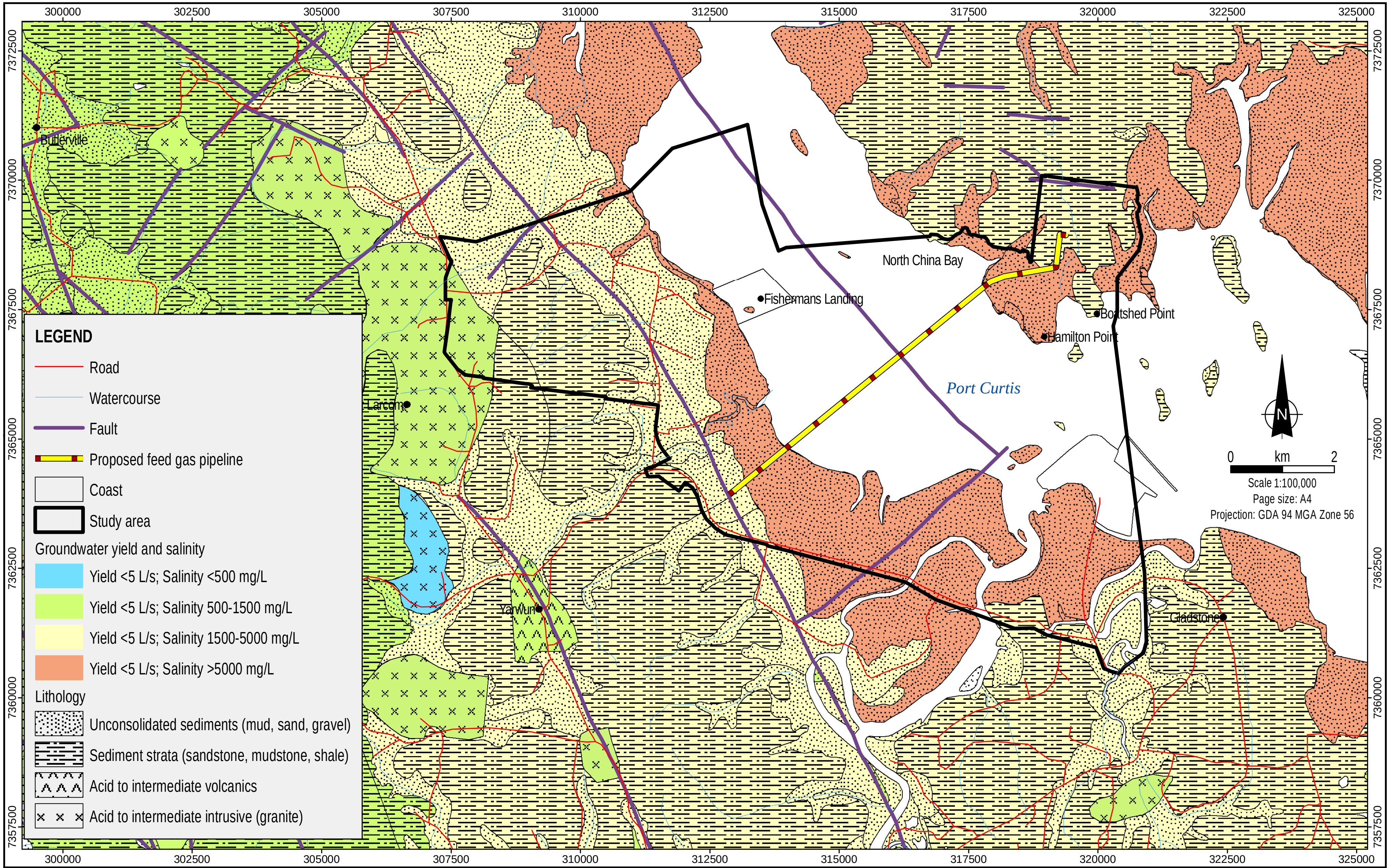
Arrow Energy

Arrow LNG Plant

arrow energy go further

Regional surface geology

Figure No: 4.1a



Source:
Place names, roads, watercourses and faults from DME.
Lithology from DME, categories interpretted by Coffey Geotechnics.
Groundwater yield and salinity modified by Coffey Geotechnics from Groundwater Resources Commission, 1987,
Groundwater Resources of Queensland (1:2,500,000)
Imagery from SPOT (2004-2007).

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Date:
24.10.2011
MXD:
7033CA_GW2_GIS011_v0_2
File Name:
7033CA_GW2_F04.1b_GIS

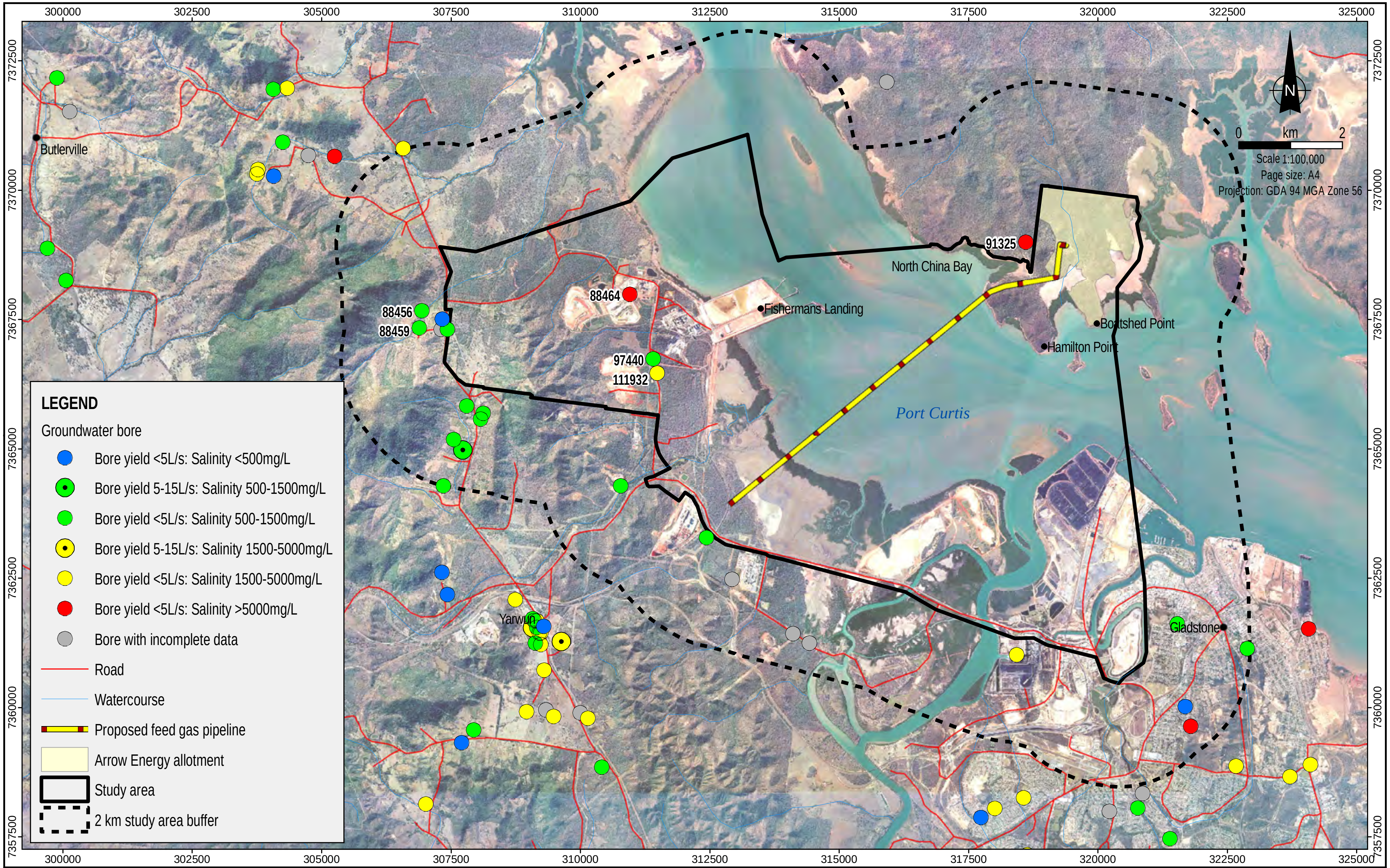
Arrow Energy

Arrow LNG Plant

arrow energy go further

Regional hydrogeology

Figure No:
4.1b



Source:
Place names, watercourses and roads from DME.
Registered groundwater bores from DERM (2010)
Imagery from SPOT (2004-2007).

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Date:
24.10.2011
MXD:
7033CA_GW2_GIS001_v0_4
File Name:
7033CA_GW2_F04.2_GIS

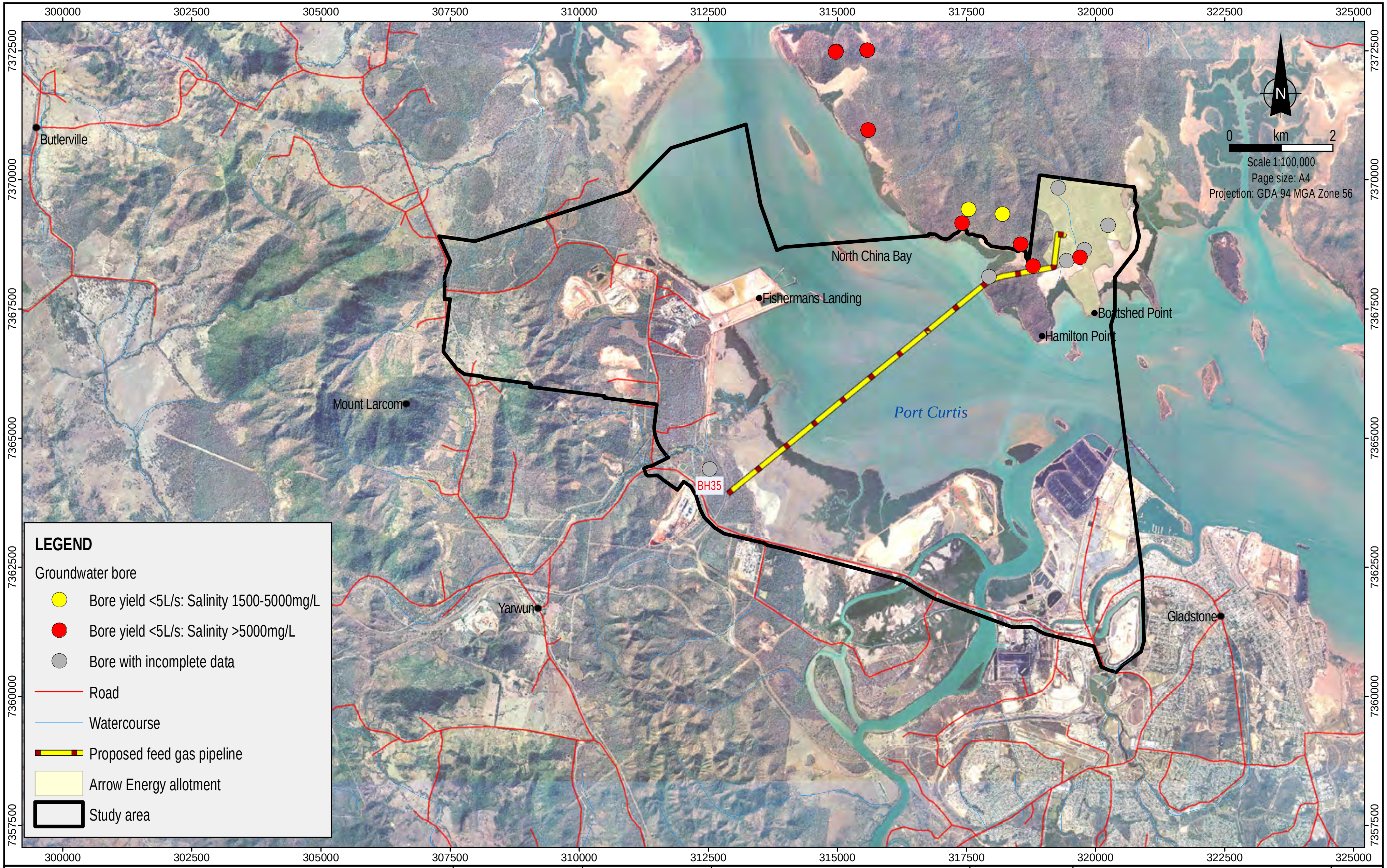
Arrow Energy

Arrow LNG Plant

arrow energy go further

Registered groundwater bores in the study area

Figure No:
4.2



Source:
Place names, watercourses and roads from DME.
Unregistered groundwater bores from Coffey and URS.
Imagery from SPOT (2004-2007).

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Date:
07.07.2011
MXD:
7033CA GW2 GIS002 v0 3
File Name:
7033CA_GW2_F04.3_GIS

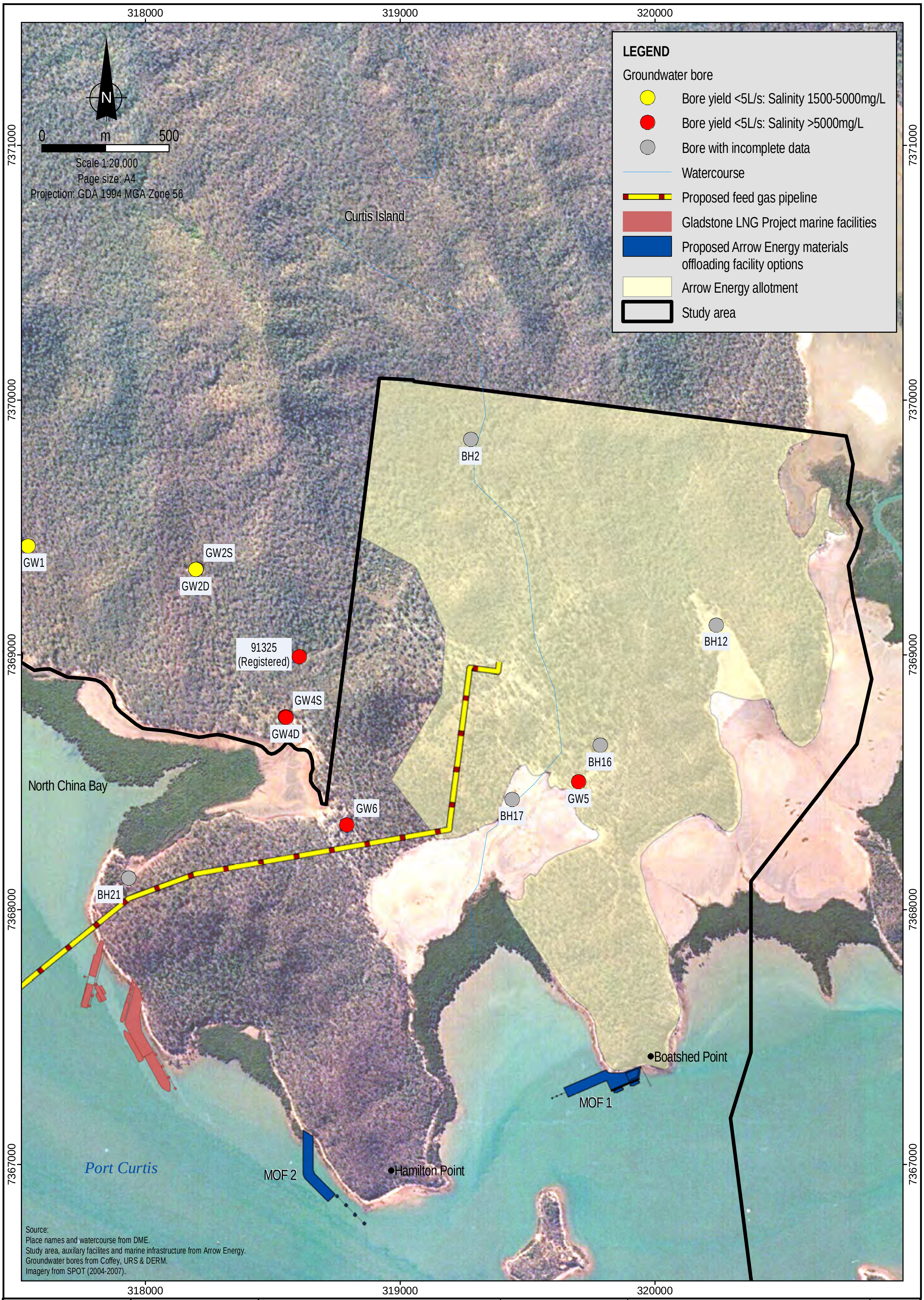
Arrow Energy

Arrow LNG Plant

arrow energy go further

Unregistered groundwater bores in the study area

Figure No:
4.3



Source:
Place names and watercourse from DME.
Study area, auxilary facilities and marine infrastructure from Arrow Energy.
Groundwater bores from Coffey, URS & DERM.
Imagery from SPOT (2004-2007).

coffey environments

Date: 24.10.2011
MXD: 7033CA_GW2_GIS003_v0_3
File Name: 7033CA_GW2_F04.4_GIS

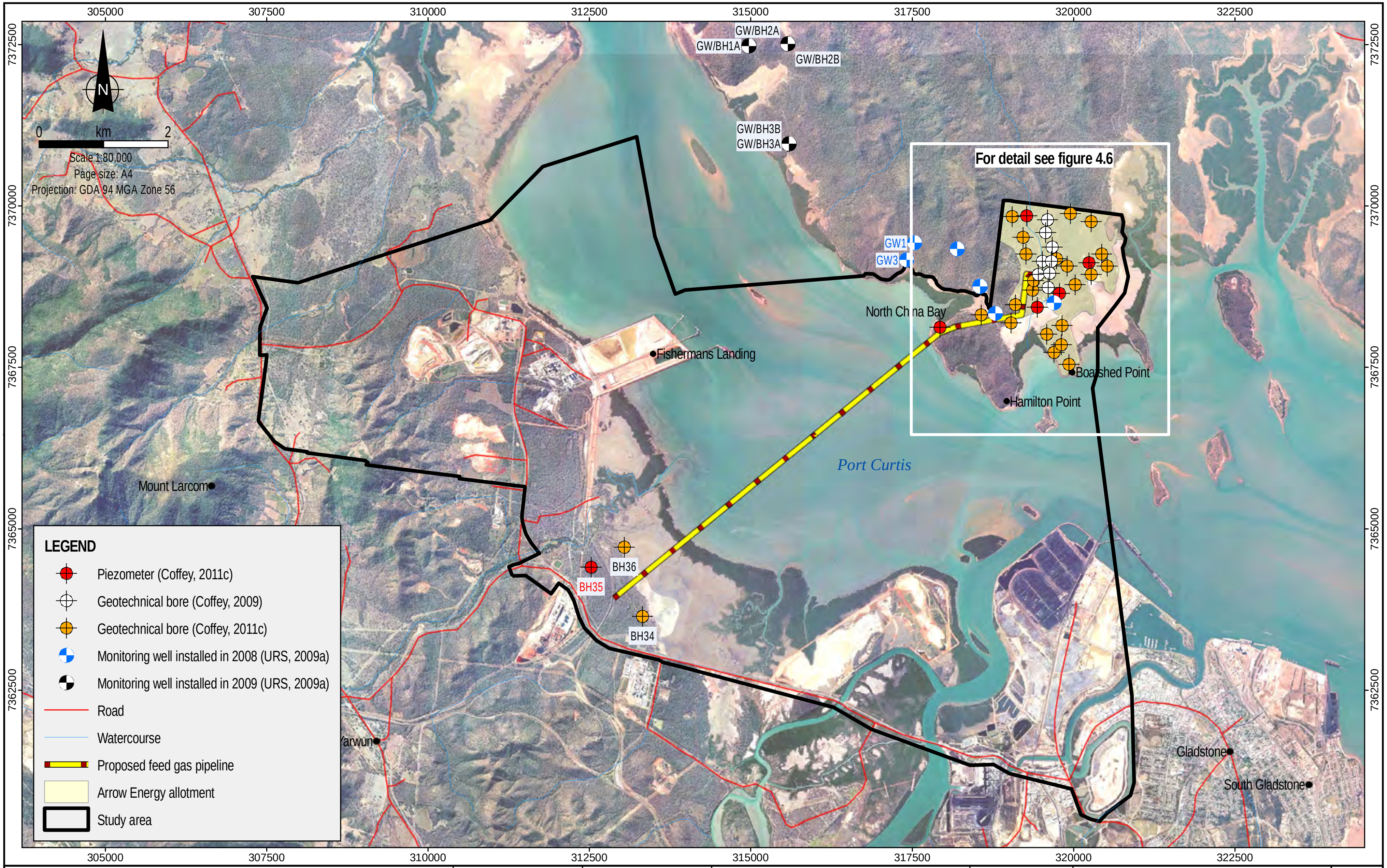
Arrow Energy

Arrow LNG Plant

arrow energy go further

Identified groundwater bores Curtis Island

Figure No: **4.4**



Source:
Place names and watercourse from DME.
Study area
Piezometers and geotechnical bores from Coffey Geotechnics.
Monitoring wells from URS (2009a).
Imagery from SPOT (2004-2007).

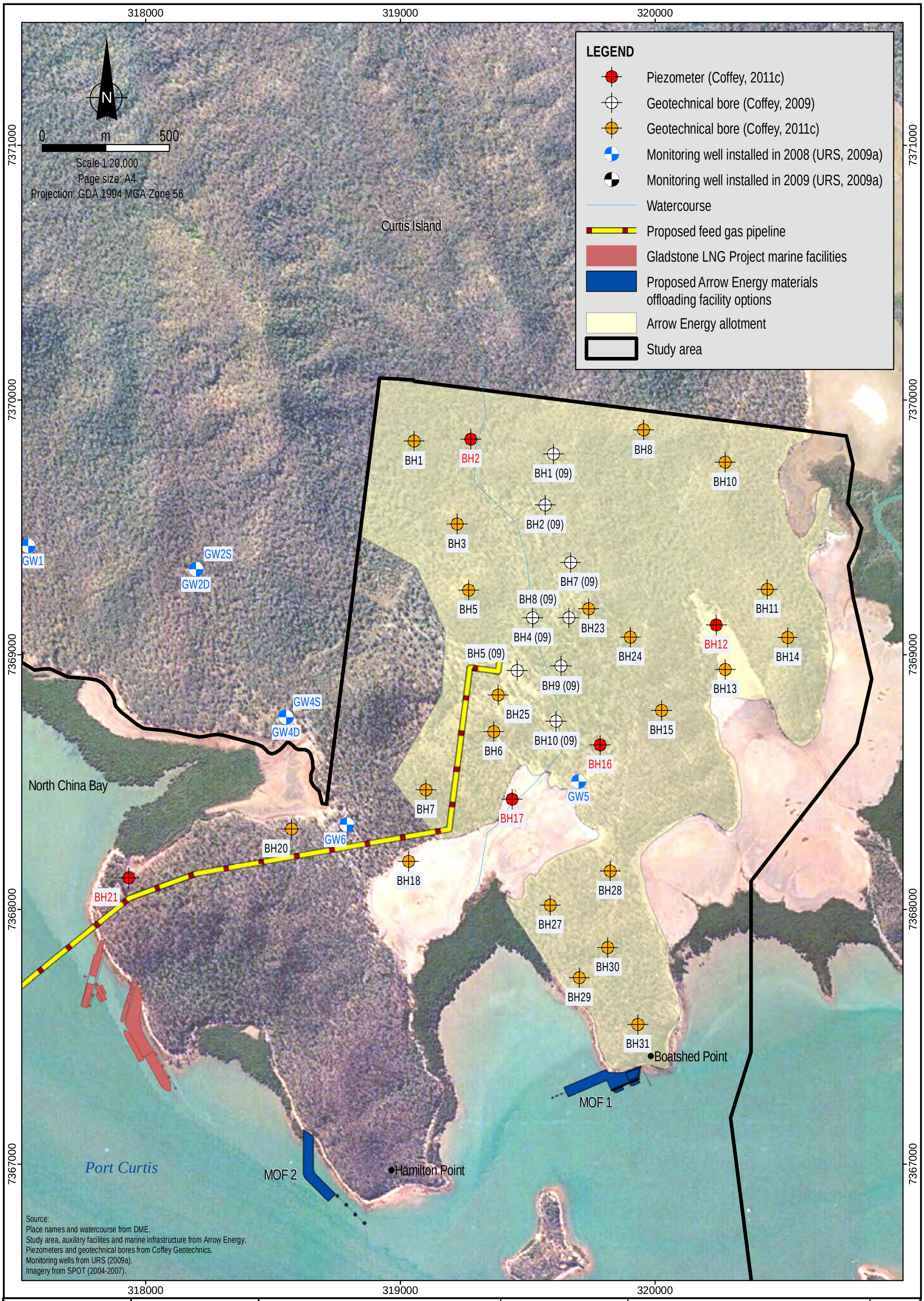
Date: 24.10.2011
MXD: 7033CA_GW2_GIS005_v0_5
File Name: 7033CA_GW2_F04.5_GIS

Arrow Energy

Arrow LNG Plant

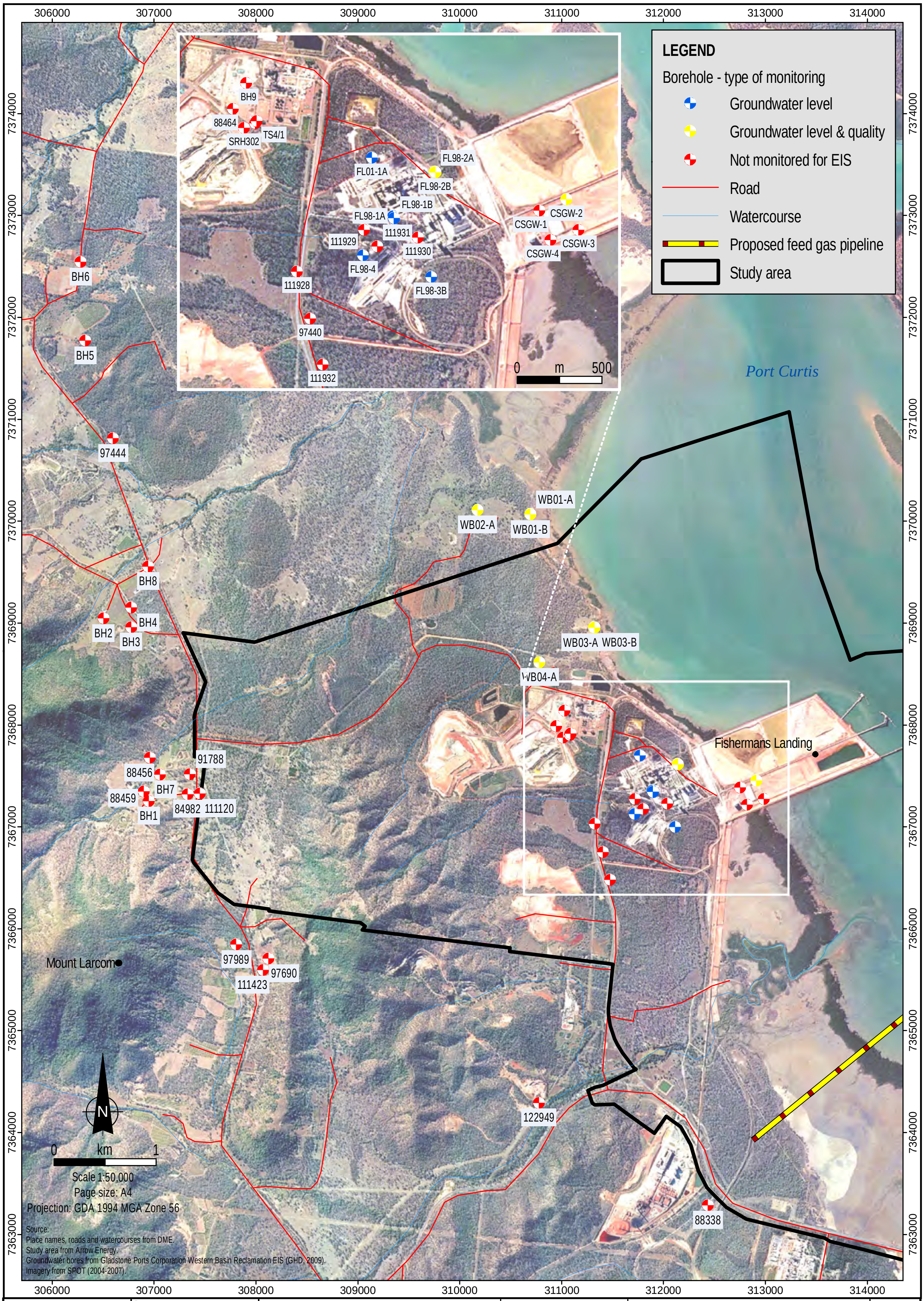
Location of Arrow LNG geotechnical bores and piezometers

Figure No: **4.5**



Source:
Place names and watercourse from DME.
Study area, auxilary facilites and marine infrastructure from Arrow Energy.
Piezometers and geotechnical bores from Coffey Geotechnics.
Monitoring wells from URS (2009a).
Imagery from SPOT (2004-2007).

coffey environments	Date: 24.10.2011 MXD: 7033CA_GW2_GIS006_v0_4 File Name: 7033CA_GW2_F04.6_GIS	Arrow Energy Arrow LNG Plant	arrow energy go further	Location of Arrow LNG geotechnical bores and piezometers (Curtis Island detail)	Figure No: 4.6



Scale 1:50,000
Page size: A4
Projection: GDA 1994 MGA Zone 56

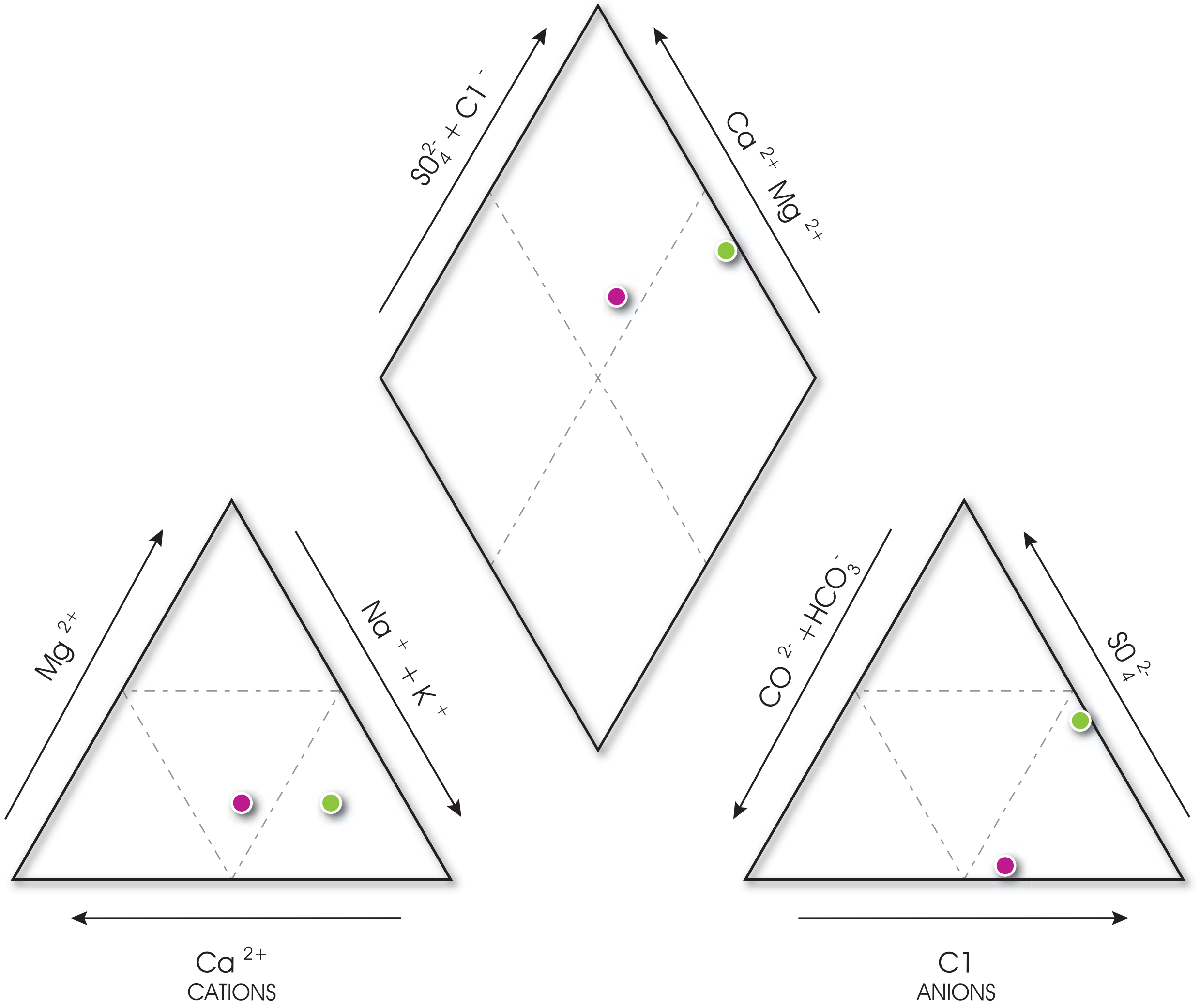
Source:
Place names, roads and watercourses from DME.
Study area from Arrow Energy.
Groundwater bores from Gladstone Ports Corporation Western Basin Reclamation EIS (GHD, 2009).
Imagery from SPOT (2004-2007).

coffey environments	Date: 24.10.2011 MXD: 7033CA_GW2_GIS007_v0_4 File Name: 7033CA_GW2_F04.7_GIS	Arrow Energy Arrow LNG Plant	Registered and unregistered bores Gladstone Ports Corporation	Figure No: 4.7

EXPLANATION

● Bore RN 88459

● Bore RN 88456



Note: Data from DERM registered bore database (accessed 2010)

coffey environments

Job No: 7033

File Name: 7033_GW2_F04.08_GL

Arrow Energy

Arrow LNG Plant

arrow energy go further

Piper diagram

Figure No: **4.8**

Appendix A

Geotechnical bore logs

coffey geotechnics

Engineering Log - Borehole

Borehole No.	**BH02**
Sheet	1 of 3
Project No:	**GEOTKPAR01651AA**
Client:	**SHELL GLOBAL SOLUTIONS**
Principal:	**ARROW ENERGY**
Project:	**ARROW ENERGY LNG PROJECT**
Borehole Location:	**REFER TO DRG GEOTKPAR01651AA/0003**
Date started:	**20.7.2010**
Date completed:	**20.7.2010**
Logged by:	**CF**
Checked by:	**SG**

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	319275.09	slope:	-90°	R.L. Surface:	24.39
hole diameter:	100 mm	Northing	7369846.39	bearing:		datum:	AHD

drilling information / **material substance**

method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetrometer kPa 100 200 300 400	structure and additional observations
ADT		C	NONE OBSERVED					ML	**SANDY SILT:** Low liquid limit, brown, fine to medium grained, with some fine grained sub-angular gravel, with some rootlets.	D	F		TOPSOIL
								CL	**GRAVELLY SANDY CLAY:** Low plasticity, brown, fine grained sand, fine to coarse grained angular gravel, trace of rootlets.		F-St		RESIDUAL SOIL
					24								
				SPT 6,14,14 N*=28					... Low plasticity, brown-orange, fine to medium grained sand, fine to medium grained angular gravel of siltstone.		VSt-H		
						1						×	DIST PP>=400kPa
				SPT 7,16,12 N*=28				CH	**SANDY CLAY:** Medium to high plasticity, grey-brown, fine to coarse grained sand, with some fine grained sub-angular gravel.				
					23							×	DIST PP>=400kPa
						2							
				SPT 4,7,7 N*=14	22								
RCB													
				SPT 27,18/120 N*=R		3		GC	**GRAVELLY CLAY:** Medium to high plasticity, brown, red, grey, fine grained angular gravel, with some medium to coarse grained sand. Gravel includes siltstone, chert and quartz fragments.				SPT - Hammer bouncing, 18 blows for 120mm
					21								
						4							
				SPT 13,10,12 N*=22				CH	**CLAY:** Medium to high plasticity, pale brown/ orange, with some laminations and with some medium to coarse grained sand.				EXTREMELY WEATHERED SILTSTONE
					20								
				SPT 13 N*=R		5					H		SPT - Hammer bouncing, 30 blows for 140mm
					19								
						6							

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit

*bit shown by suffix
e.g. ADT

support
M mud N nil
C casing

penetration
1 2 3 4
no resistance ranging to refusal

water
▼ 10/1/98 water level on date shown
► water inflow
◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Borehole

Borehole No.	**BH02**
Sheet	2 of 3
Project No:	***GEOTKPAR01651AA***
Client:	***SHELL GLOBAL SOLUTIONS***
Date started:	***20.7.2010***
Principal:	***ARROW ENERGY***
Date completed:	***20.7.2010***
Project:	***ARROW ENERGY LNG PROJECT***
Logged by:	***CF***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***
Checked by:	***SG***

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	319275.09	slope:	-90°	R.L. Surface:	24.39
hole diameter:	100 mm	Northing	7369846.39	bearing:		datum:	AHD

drilling information							**material substance**						
method	penetration 1 2 3	support	water	**notes** samples, tests, etc	RL	depth metres	graphic log	classification symbol	**material** soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	**structure and additional observations**
RCB	▨	C		SPT 30/120 N*=R	18	7	▨	CH	**CLAY:** Medium to high plasticity, pale brown/ orange, with some laminations and with some medium to coarse grained sand. *(continued)* ... with some fine grained angular gravel of highly weathered siltstone, and with some iron cementing.	D	H		SPT - Hammer bouncing, 30 blows for 120mm
					17 16 15 14 13	8 9 10 11 12			Borehole BH02 continued as cored hole				

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit
*bit shown by suffix	
e.g.	ADT

support

M	mud	N	nil
C	casing		

penetration

1 2 3 4

no resistance ranging to refusal

water

10/1/98 water level on date shown

water inflow

water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Cored Borehole

Borehole No. **BH02**
Sheet 3 of 3
Project No: **GEOTKPAR01651AA**

Client:	*SHELL GLOBAL SOLUTIONS*	Date started:	**20.7.2010**
Principal:	*ARROW ENERGY*	Date completed:	**20.7.2010**
Project:	*ARROW ENERGY LNG PROJECT*	Logged by:	**CF**
Borehole Location:	*REFER TO DRG GEOTKPAR01651AA/0003*	Checked by:	**SG**

drill model & mounting: HYDRAPOWER SCOUT   Easting: 319275.09   slope: -90°   R.L. Surface: 24.39
hole diameter: 100 mm   Drilling fluid: Northing: 7369846.39   bearing: datum: AHD

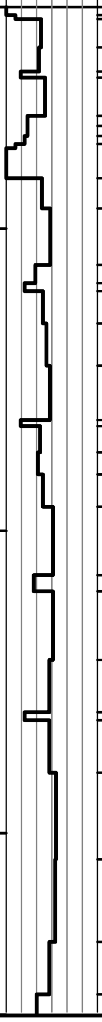
drilling information | **material substance** | **rock mass defects**

Columns: method; core-lift; water; RL; depth metres; graphic log / core recovery; material – rock type; grain characteristics, colour, structure, minor components; weathering alteration; estimated strength (VL L M H VH EH); $Is_{(50)}$ MPa (D- diametral, A- axial); RQD %; defect spacing mm (30 100 300 1000 3000); defect description – type, inclination, planarity, roughness, coating, thickness (particular / general)

RL: 18, 17, 16, 15, 14, 13
Depth (metres): 7, 8, 9, 10, 11, 12

Method: NMLC
Water: NONE OBSERVED

depth (m)	material	weathering	$Is_{(50)}$	RQD %
7	Continued from non-cored borehole			
7.0	**SANDSTONE:** Fine grained, pale brown, indistinctly bedded. Some iron staining in relict joints.	MW		64
	GRAVELLY CLAY (CL): Medium plasticity, pale brown, fine grained angular gravel of fine grained, highly weathered, medium strength, sandstone.	XW		
	SANDSTONE: Fine grained, pale brown and dark grey, indistinctly bedded. Some staining in relict joints.	MW	D 2.16	
	INTERBEDDED SILTSTONE and SANDSTONE: Fine grained, dark grey and pale grey, indistinctly bedded, staining along relict joints and bedding, with some iron staining.			89
	... with some red mottling.			92
	... with some quartz intrusions.			100



Defects (particular), in order of depth:
- JT, 60°, PL, VR, CO
- JT, 50°, PL, RO, CO
- JT2
- JT2
- JT2
- JT2
- JT1
- JT1
- JT, 25°, PL, VR, CO
- JT2
- JT1
- JT2
- JT1
- JT1
- JT1
- JT, 70°, PL, VR, SN
- JT, 75°, PL, VR, CO
- JT, 70°, PL, VR, CO
- JT, 75°, PL, RO, CO
- JT, 35°, UN, RO, CO
- JT, 75°, IR, VR, CO + SN
- JT2
- JT, 80°, PL, RO, SN
- JT2
- JT2
- JT1
- JT, 10°, PL, VR, CO
- JT2
- JT2
- JT, 15°, UN, CN

General: Generally 2 defect sets, unless otherwise indicated defects are: JT1 - JT, 35°-45°, PL, RO, CO/SN, JT2 - JT, 0°-10°, IR, CO/SN

BH02 terminated at 12m

method
DT	diatube
AS	auger screwing
AD	auger drilling
RR	roller/tricone
CB	claw or blade bit
NMLC	NMLC core
NQ, HQ, PQ	wireline core

core-lift
casing used
barrel withdrawn

graphic log/core recovery
core recovered - graphic symbols indicate material
no core recovered

water
▼ 10/1/98 water level on date shown
► water inflow
◁ partial drill fluid loss
◀ complete drill fluid loss
25 water pressure test result (lugeons) for depth interval shown

weathering
FR	fresh
SW	slightly weathered
MW	moderately weathered
HW	highly weathered
XW	extremely weathered
DW	distinctly weathered (covers MW and HW)

strength
VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

defect type
JT	joint
PT	parting
SM	seam
SZ	sheared zone
SS	sheared surface
CS	crushed seam

planarity
PL	planar
CU	curved
UN	undulating
ST	stepped
IR	irregular

roughness
VR	very rough
RO	rough
SO	smooth
SL	slickensided

coating
CN	clean
SN	stained
VN	veneer
CO	coating

coffey geotechnics

Engineering Log - Borehole

Borehole No.	**BH12**
Sheet	1 of 3
Project No:	**GEOTKPAR01651AA**
Date started:	**2.8.2010**
Date completed:	**3.8.2010**
Logged by:	**CF**
Checked by:	**SG**

Client: **SHELL GLOBAL SOLUTIONS**

Principal: **ARROW ENERGY**

Project: **ARROW ENERGY LNG PROJECT**

Borehole Location: **REFER TO DRG GEOTKPAR01651AA/0003**

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	320238.76	slope:	-90°	R.L. Surface:	2.16
hole diameter:	100 mm	Northing	7369118.22	bearing:		datum:	AHD

drilling information | **material substance**

method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	structure and additional observations
ADT		C		ASS	2			CL	**SILTY CLAY:** low to medium plasticity, brown, some fine grained sand, trace of organics.	D/M	F		TOPSOIL (MUD FLATS)
				ASS				CH	**SILTY CLAY:** high plasticity, brown/pale brown, trace of fine grained sand, some organics.	M	VS		MARINE DEPOSIT ASS samples taken at 0.25m intervals between 0.0 - 3.5m 450mm recovered
				U_{50}									
			2:20pm	ASS									
						1			...colour changing to grey/blue.	W		×	PP=10kPa 450mm recovered
				U_{50}	1								
				ASS							F	×	ALLUVIUM PP=80kPa 450mm recovered
				U_{50}				CL	**SILTY CLAY:** medium plasticity, grey/blue, trace of fine grained sand, some organics.				
				ASS						M	VSt		
RCB				U_{50}	0	2			...colour changing to grey/brown.			×	PP=250kPa 450mm recovered
		M		ASS					... gravel layer 2.3 to 2.5m - fine grained sub-angular.			× ×	PP=300kPa 450mm recovered PP>400kPa
				SPT 3,7,9 N*=16					...with some fine to medium grained sand.				
				SPT 2,10,23 N*=33	-1	3							450mm recovered
								GC	**CLAYEY GRAVEL:** fine to medium grained angular to subangular, brown/grey/red, medium plasticity clay.		D		
								CL	**SILTY CLAY:** medium plasticity, grey/brown, with some fine to medium grained sand, trace of fine grained angular gravel.		VSt		RESIDUAL SOIL
				SPT 3,9,10 N*=19	-2	4			...iron staining and cement visable on siltstone fragments.				EXTREMELY WEATHERED SILTSTONE/SANDSTONE 450mm recovered
								CL	**GRAVELLY CLAY:** medium to low plasticity, orange/grey, fine grained angular siltstone gravel.		H		
						5						×	PP=400kPa
					-3				Borehole BH12 continued as cored hole				
						6							

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit
*bit shown by suffix	
e.g.	ADT

support

M mud N nil
C casing

penetration

1 2 3 4
no resistance ranging to refusal

water

▼ 10/1/98 water level on date shown

► water inflow

◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

PROJECT FILE: GEOTKPAR01651AA_ONSHORE.GPJ. LIBRARY FILE: COFGEOTECHVER7REV3COLOUR.GLB. TEMPLATE FILE: COFFEY.GDT FRAME TITLE: BOREHOLE. DATE: 30.5.11

coffey geotechnics

Engineering Log - Cored Borehole

Borehole No.	***BH12***
Sheet	2 of 3
Project No:	***GEOTKPAR01651AA***

Client:	***SHELL GLOBAL SOLUTIONS***	Date started:	***2.8.2010***
Principal:	***ARROW ENERGY***	Date completed:	***3.8.2010***
Project:	***ARROW ENERGY LNG PROJECT***	Logged by:	***CF***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***	Checked by:	***SG***

drill model & mounting: HYDRAPOWER SCOUT | Easting: 320238.76 | slope: -90° | R.L. Surface: 2.16

hole diameter: 100 mm | Drilling fluid: | Northing: 7369118.22 | bearing: | datum: AHD

drilling information | **material substance** | **rock mass defects**

Columns: method | core-lift | water | RL | depth metres | graphic log core recovery | **material** rock type; grain characteristics, colour, structure, minor components | weathering alteration | estimated strength VL L M H VH EH | Is(50) MPa D- diametral A- axial | RQD % | defect spacing mm 30 100 300 1000 3000 | **defect description** type, inclination, planarity, roughness, coating, thickness — particular / general

RL: 2, 1, 0, -1, -2, -3

depth: 1, 2, 3, 4, 5, 6

water: 2:20pm

Continued from non-cored borehole

method: NMLC

SANDSTONE: fine grained, pale brown, indistinctly bedded, with some iron staining of relict fractures, bleaching along open defects. — HW / XW / HW

CLAYEY GRAVEL (GC): fine grained, brown, sub-angular to angular, low plasticity clay. — XW

SANDSTONE: fine grained, pale brown, indistinctly bedded, with some iron staining of relict fractures, bleaching along open — MW

RQD %: 0, 11

Defects (particular):
- JT1
- JT1
- JT, 20°, IR, VR, CO
- JT, 20°, ST, VR, CO
- JT, 60°, PL, RO, CO
- JT, 60°, CU, RO, CO
- JT, 30°, PL, RO, CO
- JT, 80°, IR, VR, CO
- JT1
- 5.84 to 5.92 - Highly fractured,

General: Generally 2 defect sets, unless otherwise indicated defects are:
JT1 - JT, 5-15°, IR, VR, CO/SN; and JT2 - JT, 40-50°, PL, RO, CO/SN

method	
DT	diatube
AS	auger screwing
AD	auger drilling
RR	roller/tricone
CB	claw or blade bit
NMLC	NMLC core
NQ, HQ, PQ	wireline core

core-lift
- casing used
- barrel withdrawn

graphic log/core recovery
- core recovered - graphic symbols indicate material
- no core recovered

water
- 10/1/98 water level on date shown
- water inflow
- partial drill fluid loss
- complete drill fluid loss
- 25 water pressure test result (lugeons) for depth interval shown

weathering	
FR	fresh
SW	slightly weathered
MW	moderately weathered
HW	highly weathered
XW	extremely weathered
DW	distinctly weathered (covers MW and HW)

strength	
VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

defect type	
JT	joint
PT	parting
SM	seam
SZ	sheared zone
SS	sheared surface
CS	crushed seam

planarity	
PL	planar
CU	curved
UN	undulating
ST	stepped
IR	irregular

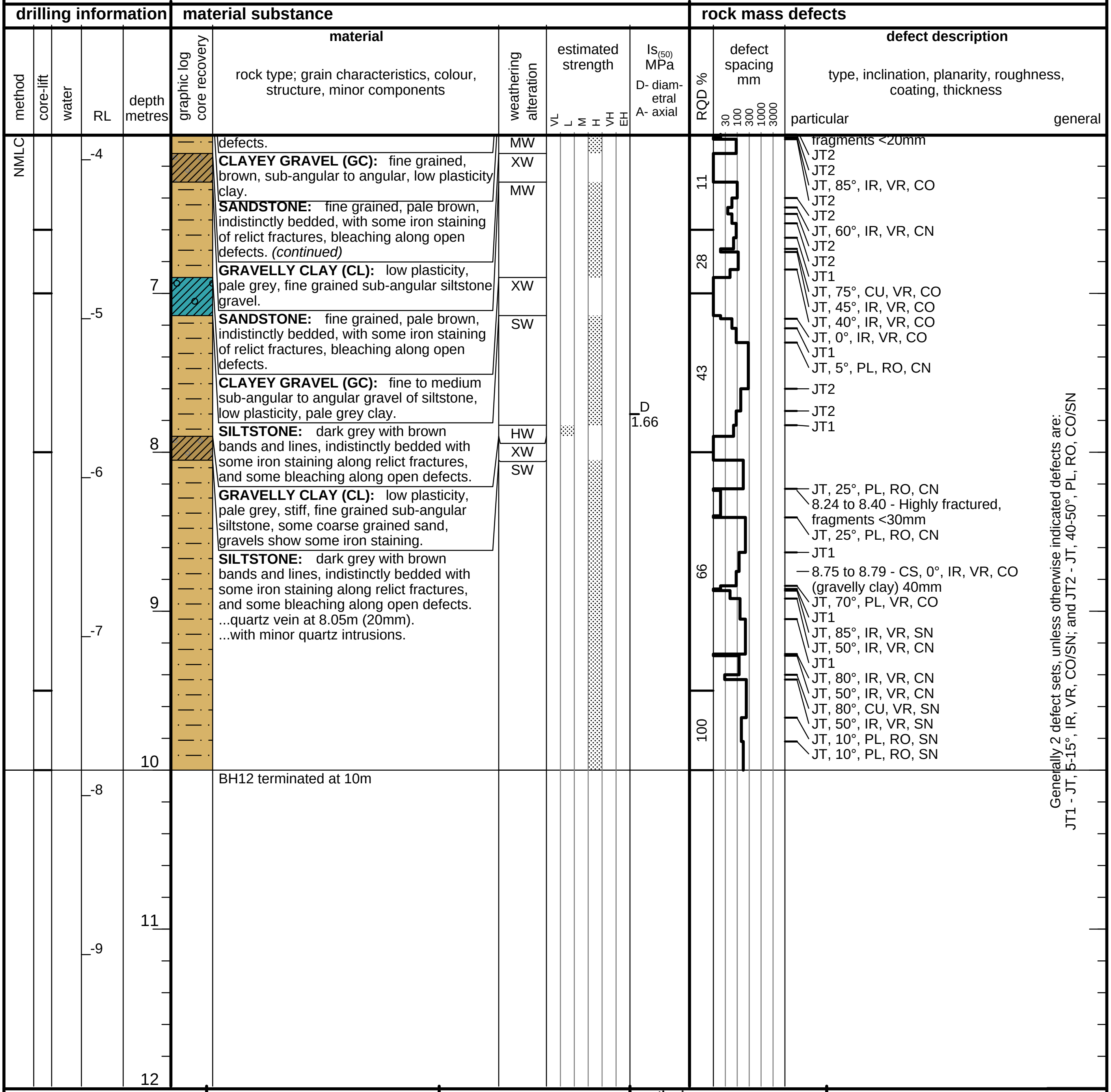
roughness	
VR	very rough
RO	rough
SO	smooth
SL	slickensided

coating	
CN	clean
SN	stained
VN	veneer
CO	coating

Engineering Log - Cored Borehole

Borehole No.	**BH12**
Sheet	3 of 3
Project No:	**GEOTKPAR01651AA**
Client:	**SHELL GLOBAL SOLUTIONS**
Principal:	**ARROW ENERGY**
Project:	**ARROW ENERGY LNG PROJECT**
Borehole Location:	**REFER TO DRG GEOTKPAR01651AA/0003**
Date started:	**2.8.2010**
Date completed:	**3.8.2010**
Logged by:	**CF**
Checked by:	**SG**

drill model & mounting: HYDRAPOWER SCOUT
Easting: 320238.76
slope: -90°
R.L. Surface: 2.16
hole diameter: 100 mm
Drilling fluid:
Northing: 7369118.22
bearing:
datum: AHD



material — rock type; grain characteristics, colour, structure, minor components

defects.

CLAYEY GRAVEL (GC): fine grained, brown, sub-angular to angular, low plasticity clay.

SANDSTONE: fine grained, pale brown, indistinctly bedded, with some iron staining of relict fractures, bleaching along open defects. *(continued)*

GRAVELLY CLAY (CL): low plasticity, pale grey, fine grained sub-angular siltstone gravel.

SANDSTONE: fine grained, pale brown, indistinctly bedded, with some iron staining of relict fractures, bleaching along open defects.

CLAYEY GRAVEL (GC): fine to medium sub-angular to angular gravel of siltstone, low plasticity, pale grey clay.

SILTSTONE: dark grey with brown bands and lines, indistinctly bedded with some iron staining along relict fractures, and some bleaching along open defects.

GRAVELLY CLAY (CL): low plasticity, pale grey, stiff, fine grained sub-angular siltstone, some coarse grained sand, gravels show some iron staining.

SILTSTONE: dark grey with brown bands and lines, indistinctly bedded with some iron staining along relict fractures, and some bleaching along open defects.
...quartz vein at 8.05m (20mm).
...with minor quartz intrusions.

BH12 terminated at 10m

weathering alteration: MW, XW, MW, XW, SW, HW, XW, SW

defect description — type, inclination, planarity, roughness, coating, thickness

particular

fragments <20mm
JT2
JT2
JT, 85°, IR, VR, CO
JT2
JT2
JT, 60°, IR, VR, CN
JT2
JT2
JT1
JT, 75°, CU, VR, CO
JT, 45°, IR, VR, CO
JT, 40°, IR, VR, CO
JT, 0°, IR, VR, CO
JT1
JT, 5°, PL, RO, CN
JT2
JT2
JT1
JT, 25°, PL, RO, CN
8.24 to 8.40 - Highly fractured, fragments <30mm
JT, 25°, PL, RO, CN
JT1
8.75 to 8.79 - CS, 0°, IR, VR, CO (gravelly clay) 40mm
JT, 70°, PL, VR, CO
JT1
JT, 85°, IR, VR, SN
JT, 50°, IR, VR, CN
JT1
JT, 80°, IR, VR, CN
JT, 50°, IR, VR, CN
JT, 80°, CU, VR, SN
JT, 50°, IR, VR, SN
JT, 10°, PL, RO, SN
JT, 10°, PL, RO, SN

general

Generally 2 defect sets, unless otherwise indicated defects are:
JT1 - JT, 5-15°, IR, VR, CO/SN; and JT2 - JT, 40-50°, PL, RO, CO/SN

method

DT	diatube
AS	auger screwing
AD	auger drilling
RR	roller/tricone
CB	claw or blade bit
NMLC	NMLC core
NQ, HQ, PQ	wireline core

core-lift

casing used

barrel withdrawn

graphic log/core recovery

core recovered - graphic symbols indicate material

no core recovered

water

▼ 10/1/98 water level on date shown

► water inflow

◁ partial drill fluid loss

◀ complete drill fluid loss

25 water pressure test result (lugeons) for depth interval shown

weathering

FR	fresh
SW	slightly weathered
MW	moderately weathered
HW	highly weathered
XW	extremely weathered
DW	distinctly weathered (covers MW and HW)

strength

VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

defect type

JT	joint
PT	parting
SM	seam
SZ	sheared zone
SS	sheared surface
CS	crushed seam

planarity

PL	planar
CU	curved
UN	undulating
ST	stepped
IR	irregular

roughness

VR	very rough
RO	rough
SO	smooth
SL	slickensided

coating

CN	clean
SN	stained
VN	veneer
CO	coating

coffey geotechnics

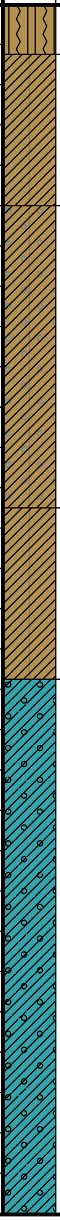
Engineering Log - Borehole

Borehole No.	***BH16***
Sheet	1 of 5
Project No:	***GEOTKPAR01651AA***
Date started:	***30.7.2010***
Date completed:	***31.7.2010***
Logged by:	***SH***
Checked by:	***SG***

Client:	***SHELL GLOBAL SOLUTIONS***
Principal:	***ARROW ENERGY***
Project:	***ARROW ENERGY LNG PROJECT***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	319783.84	slope:	-90°	R.L. Surface:	3.30
hole diameter:	100 mm	Northing	7368646.48	bearing:		datum:	AHD

drilling information / **material substance**



method	penetration 1 2 3	support	water	**notes** samples, tests, etc	RL	depth metres	classification symbol	**material** soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	**structure and additional observations**
ADT		C	NONE OBSERVED				CH	**CLAY:** high plasticity, brown, trace of fine to coarse grained sand and fine grained gravel.	D	St		TOPSOIL
					3							
							CH	**SILTY CLAY:** high plasticity, brown, trace of fine to coarse grained sand.				ALLUVIUM
				SPT 5,5,4 N*=9								
									M			
				SPT 2,3,4 N*=7		1	CL	**GRAVELLY SILTY CLAY:** low to medium plasticity, brown with red/orange mottling, fine grained sub-angular gravel.				RESIDUAL
					2							
											×	DIST PP=280kPa
				SPT 2,4,13 N*=17	1	2				VSt		
							CL	**SILTY CLAY:** low plasticity, grey and orange mottled, trace of fine to medium grained sand.				
				U_{50}	0	3						
							GP	**CLAYEY SANDY GRAVEL:** fine to medium grained, brown/red, fine to coarse grained sand, medium plasticity clay fines.		VD	×	PP=260kPa
RCB				SPT 9,12,26 N*=38	-1	4						
				SPT 18,25,16 N*=41	-2	5						
						6						

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit

*bit shown by suffix
e.g. ADT

support

M	mud	N	nil
C	casing		

penetration
1 2 3 4
no resistance ranging to refusal

water

▼ 10/1/98 water level on date shown

► water inflow

◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

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Engineering Log - Borehole

Borehole No. **BH16**
Sheet 2 of 5
Project No: **GEOTKPAR01651AA**

Client:	*SHELL GLOBAL SOLUTIONS*
Principal:	*ARROW ENERGY*
Project:	*ARROW ENERGY LNG PROJECT*
Borehole Location:	*REFER TO DRG GEOTKPAR01651AA/0003*
Date started:	*30.7.2010*
Date completed:	*31.7.2010*
Logged by:	*SH*
Checked by:	*SG*

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	319783.84	slope:	-90°	R.L. Surface:	3.30
hole diameter:	100 mm	Northing	7368646.48	bearing:		datum:	AHD

drilling information | **material substance**

method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	structure and additional observations
RCB		C		SPT 22,25,18 N*=43	-3		▨	GP	**CLAYEY SANDY GRAVEL:** fine to medium grained, brown/red, fine to coarse grained sand, medium plasticity clay fines. *(continued)*	M	VD		
							▨	GC	**CLAYEY GRAVEL:** fine to medium grained, brown/orange, high plasticity clay. Trace of fine to coarse grained sand.				EXTREMELY WEATHERED SANDSTONE with highly weathered zones below 7.2m
		N		SPT 30/110 N=R	-4	7	▨						SPT - 30 blows/110mm
						8	▨						
				SPT 30/110 N=R	-5		▨	CH	**GRAVELLY CLAY:** high plasticity, grey, fine grained sub-angular gravel.		H		SPT - 30 blows/110mm
									Borehole BH16 continued as cored hole				
					-6	9							
					-7	10							
					-8	11							
						12							

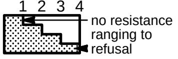
method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit
*bit shown by suffix	
e.g.	ADT

support

M mud N nil
C casing

penetration



water

▼ 10/1/98 water level on date shown
► water inflow
◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

PROJECT FILE: GEOTKPAR01651AA_ONSHORE.GPJ. LIBRARY FILE: COFGEOTECHVER7REV3COLOUR.GLB. TEMPLATE FILE: COFFEY.GDT FRAME TITLE: BOREHOLE. DATE: 29.5.11

Form GEO 5.3 Issue 3 Rev.2

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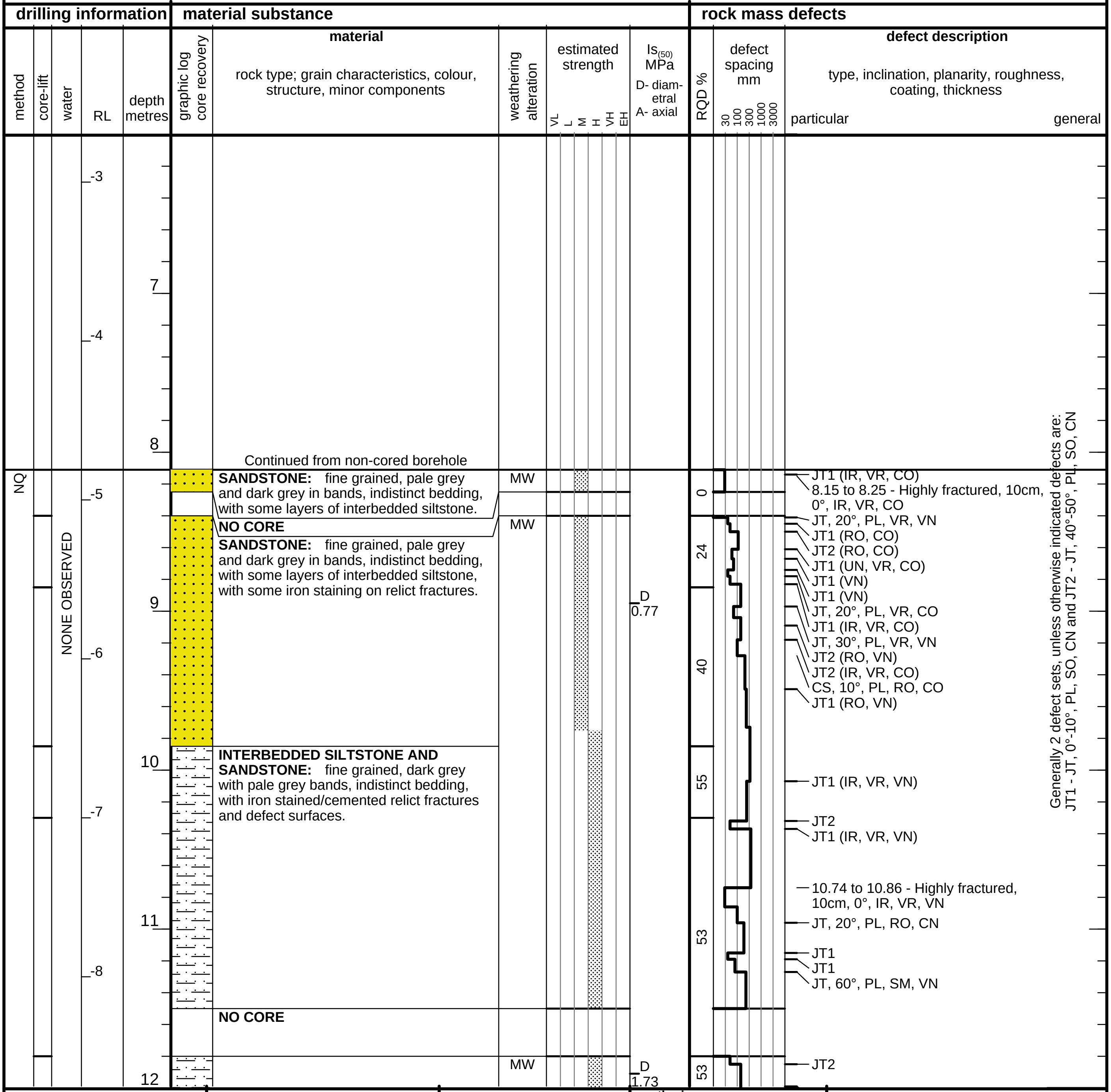
Engineering Log - Cored Borehole

Borehole No. **BH16**
Sheet 3 of 5
Project No: **GEOTKPAR01651AA**

Client: **SHELL GLOBAL SOLUTIONS**
Principal: **ARROW ENERGY**
Project: **ARROW ENERGY LNG PROJECT**
Borehole Location: **REFER TO DRG GEOTKPAR01651AA/0003**

Date started: **30.7.2010**
Date completed: **31.7.2010**
Logged by: **SH**
Checked by: **SG**

drill model & mounting: HYDRAPOWER SCOUT
Easting: 319783.84
slope: -90°
R.L. Surface: 3.30
hole diameter: 100 mm
Drilling fluid:
Northing: 7368646.48
bearing:
datum: AHD



drilling information | **material substance** | **rock mass defects**

method	core-lift	water	RL	depth metres	graphic log / core recovery	material: rock type; grain characteristics, colour, structure, minor components	weathering alteration	estimated strength (VL L M H VH EH)	Is(50) MPa (D- diametral, A- axial)	RQD %	defect spacing mm (30 100 300 1000 3000)	defect description: type, inclination, planarity, roughness, coating, thickness (particular / general)
			-3									
			-4	7								
				8		Continued from non-cored borehole						
NQ		NONE OBSERVED	-5			**SANDSTONE:** fine grained, pale grey and dark grey in bands, indistinct bedding, with some layers of interbedded siltstone.	MW			0		JT1 (IR, VR, CO) 8.15 to 8.25 - Highly fractured, 10cm, 0°, IR, VR, CO
						NO CORE						
						SANDSTONE: fine grained, pale grey and dark grey in bands, indistinct bedding, with some layers of interbedded siltstone, with some iron staining on relict fractures.	MW			24		JT, 20°, PL, VR, VN JT1 (RO, CO) JT2 (RO, CO) JT1 (UN, VR, CO) JT1 (VN) JT1 (VN)
			-6	9					D 0.77	40		JT, 20°, PL, VR, CO JT1 (IR, VR, CO) JT, 30°, PL, VR, VN JT2 (RO, VN) JT2 (IR, VR, CO) CS, 10°, PL, RO, CO JT1 (RO, VN)
				10		**INTERBEDDED SILTSTONE AND SANDSTONE:** fine grained, dark grey with pale grey bands, indistinct bedding, with iron stained/cemented relict fractures and defect surfaces.				55		JT1 (IR, VR, VN) JT2 JT1 (IR, VR, VN)
			-7									10.74 to 10.86 - Highly fractured, 10cm, 0°, IR, VR, VN
			-8	11						53		JT, 20°, PL, RO, CN JT1 JT1 JT, 60°, PL, SM, VN
						NO CORE						
				12			MW		D 1.73	53		JT2

Generally 2 defect sets, unless otherwise indicated defects are: JT1 - JT, 0°-10°, PL, SO, CN and JT2 - JT, 40°-50°, PL, SO, CN

method

DT	diatube
AS	auger screwing
AD	auger drilling
RR	roller/tricone
CB	claw or blade bit
NMLC	NMLC core
NQ, HQ, PQ	wireline core

core-lift
casing used
barrel withdrawn

graphic log/core recovery
core recovered - graphic symbols indicate material
no core recovered

water
10/1/98 water level on date shown
water inflow
partial drill fluid loss
complete drill fluid loss
water pressure test result (lugeons) for depth interval shown

weathering

FR	fresh
SW	slightly weathered
MW	moderately weathered
HW	highly weathered
XW	extremely weathered
DW	distinctly weathered (covers MW and HW)

strength

VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

defect type

JT	joint
PT	parting
SM	seam
SZ	sheared zone
SS	sheared surface
CS	crushed seam

roughness

VR	very rough
RO	rough
SO	smooth
SL	slickensided

planarity

PL	planar
CU	curved
UN	undulating
ST	stepped
IR	irregular

coating

CN	clean
SN	stained
VN	veneer
CO	coating

Engineering Log - Cored Borehole

Borehole No.	**BH16**
Sheet	4 of 5
Project No:	***GEOTKPAR01651AA***
Client:	***SHELL GLOBAL SOLUTIONS***
Principal:	***ARROW ENERGY***
Project:	***ARROW ENERGY LNG PROJECT***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***
Date started:	***30.7.2010***
Date completed:	***31.7.2010***
Logged by:	***SH***
Checked by:	***SG***

drill model & mounting:	HYDRAPOWER SCOUT	Easting:	319783.84	slope:	-90°
R.L. Surface:	3.30				
hole diameter:	100 mm	Drilling fluid:		Northing:	7368646.48
bearing:		datum:	AHD		

drilling information | material substance | rock mass defects

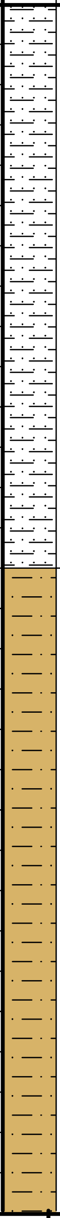
Columns: method | core-lift | water | RL | depth metres | graphic log core recovery | material: rock type; grain characteristics, colour, structure, minor components | weathering alteration | estimated strength (VL L M H VH EH) | $Is_{(50)}$ MPa (D- diametral, A- axial) | RQD % | defect spacing mm (30 100 300 1000 3000) | defect description: type, inclination, planarity, roughness, coating, thickness (particular / general)

method: NQ

water: NONE OBSERVED

RL: -9, -10, -11, -12, -13, -14

depth metres: 13, 14, 15, 16, 17, 18

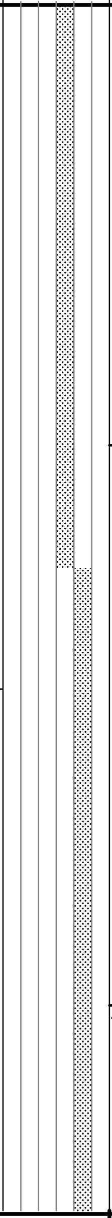


INTERBEDDED SILTSTONE AND SANDSTONE: fine grained, dark grey with pale grey bands, indistinct bedding, with iron stained/cemented relict fractures and defect surfaces. *(continued)*

SILTSTONE: dark grey with pale grey bands, distinctly laminated, with some interbedded sandstone layers, and with some iron stained or coated relict fractures and defect surfaces.

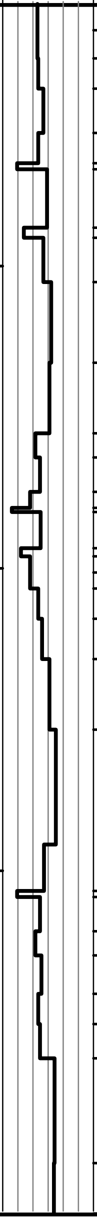
...minor iron staining and joint surfaces mostly clean.

weathering alteration: MW; SW



$Is_{(50)}$ MPa: D 1.49; D 4.06

RQD %: 53; 53; 83; 88



defect description, particular:

- JT1 (IR, VR, VN)
- JT1
- JT1 (IR, RO, VN)
- JT, 20°, PL, SM, CN
- JT, 30°, PL, SM, VN
- JT, 30°, PL, RO, VN
- JT, 20°, IR, VR, CO
- JT1 (IR, VR, VN)
- JT1 (UN)
- JT2
- JT, 20°, PL, SM, CN
- JT1 (RO, VN)
- JT, 30°, IR, VR, CO
- JT, 20°, PL, VR, VN
- JT1 (IR, VR, VN)
- JT2
- JT1
- JT1 (RO)
- JT (UN)
- JT1 (RO)
- JT, 60°, PL, RO, VN
- JT1
- JT, 30°, IR, VR, VN
- 16.17 to 16.2 - CS, 0°, PL, VR, CO
- JT1 (RO, VN)
- JT1 (IR, RO, VN)
- JT1
- JT1 (IR, RO)
- JT2
- JT1
- JT1
- JT1 (IR, RO)

general: Generally 2 defect sets, unless otherwise indicated defects are: JT1 - JT, 0°-10°, PL, SO, CN and JT2 - JT, 40°-50°, PL, SO, CN

method

DT	diatube
AS	auger screwing
AD	auger drilling
RR	roller/tricone
CB	claw or blade bit
NMLC	NMLC core
NQ, HQ, PQ	wireline core

core-lift

- casing used
- barrel withdrawn

graphic log/core recovery

- core recovered - graphic symbols indicate material
- no core recovered

water

- 10/1/98 water level on date shown
- water inflow
- partial drill fluid loss
- complete drill fluid loss
- 25 water pressure test result (lugeons) for depth interval shown

weathering

FR	fresh
SW	slightly weathered
MW	moderately weathered
HW	highly weathered
XW	extremely weathered
DW	distinctly weathered (covers MW and HW)

strength

VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

defect type

JT	joint
PT	parting
SM	seam
SZ	sheared zone
SS	sheared surface
CS	crushed seam

planarity

PL	planar
CU	curved
UN	undulating
ST	stepped
IR	irregular

roughness

VR	very rough
RO	rough
SO	smooth
SL	slickensided

coating

CN	clean
SN	stained
VN	veneer
CO	coating

PROJECT FILE: GEOTKPAR01651AA_ONSHORE.GPJ. LIBRARY FILE: COFGEOTECHVER7REV3COLOUR.GLB. TEMPLATE FILE: COFFEY.GDT FRAME TITLE: CORED BOREHOLE. DATE: 17.2.11

Form GEO 5.5 Issue 3 Rev. 3

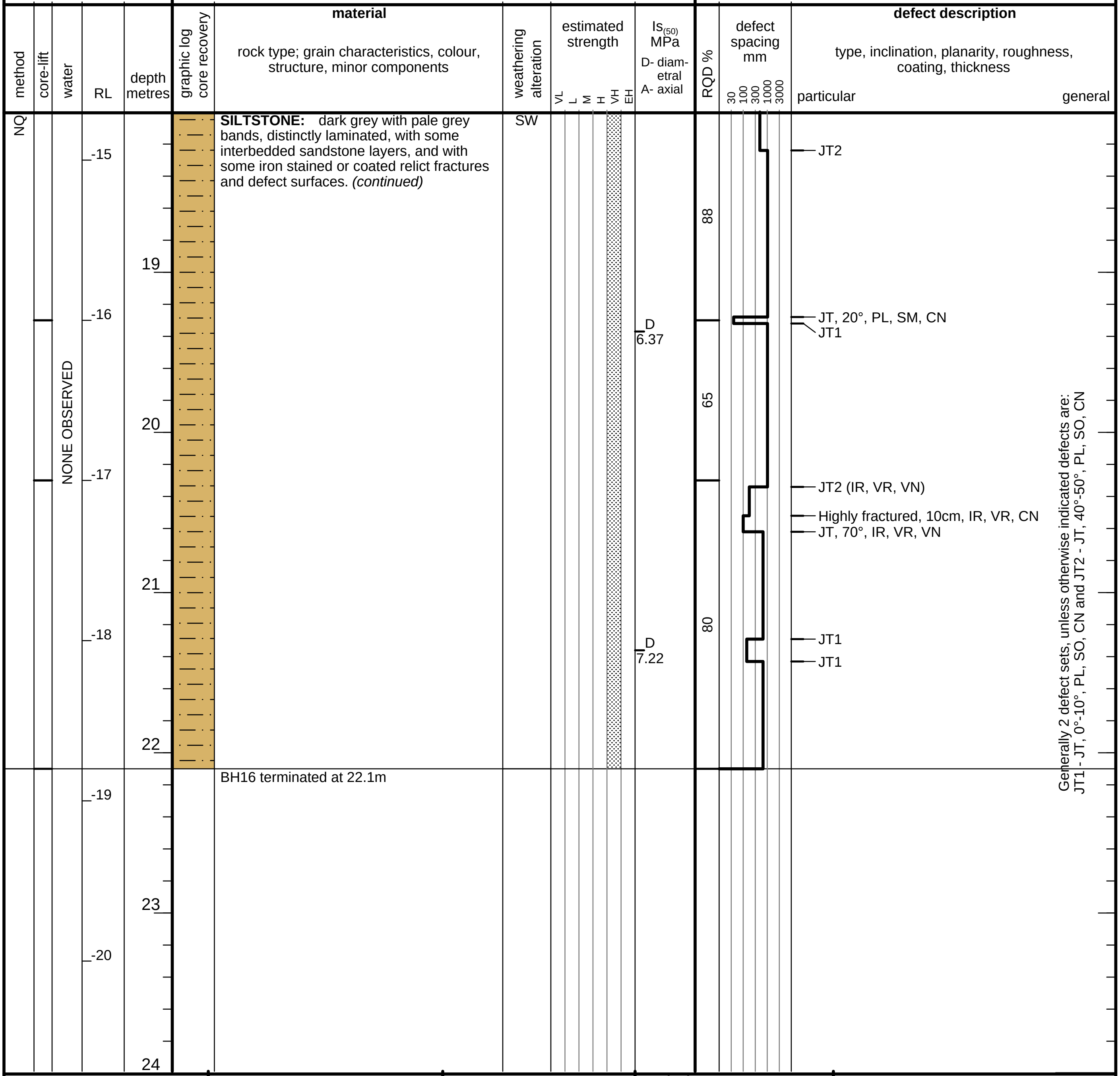
coffey geotechnics

Engineering Log - Cored Borehole

Borehole No.	**BH16**
Sheet	5 of 5
Project No:	**GEOTKPAR01651AA**
Client:	**SHELL GLOBAL SOLUTIONS**
Date started:	**30.7.2010**
Principal:	**ARROW ENERGY**
Date completed:	**31.7.2010**
Project:	**ARROW ENERGY LNG PROJECT**
Logged by:	**SH**
Borehole Location:	**REFER TO DRG GEOTKPAR01651AA/0003**
Checked by:	**SG**

drill model & mounting:HYDRAPOWER SCOUT
Easting: 319783.84
slope: -90°
R.L. Surface: 3.30
hole diameter: 100 mm
Drilling fluid:
Northing: 7368646.48
bearing:
datum: AHD

drilling information | **material substance** | **rock mass defects**



material — rock type; grain characteristics, colour, structure, minor components

SILTSTONE: dark grey with pale grey bands, distinctly laminated, with some interbedded sandstone layers, and with some iron stained or coated relict fractures and defect surfaces. *(continued)* — SW

D 6.37

D 7.22

BH16 terminated at 22.1m

defect description — type, inclination, planarity, roughness, coating, thickness

particular:

- JT2
- JT, 20°, PL, SM, CN
- JT1
- JT2 (IR, VR, VN)
- Highly fractured, 10cm, IR, VR, CN
- JT, 70°, IR, VR, VN
- JT1
- JT1

general:

Generally 2 defect sets, unless otherwise indicated defects are: JT1 - JT, 0°-10°, PL, SO, CN and JT2 - JT, 40°-50°, PL, SO, CN

method

DT	diatube
AS	auger screwing
AD	auger drilling
RR	roller/tricone
CB	claw or blade bit
NMLC	NMLC core
NQ, HQ, PQ	wireline core

core-lift

casing used

barrel withdrawn

graphic log/core recovery

core recovered - graphic symbols indicate material

no core recovered

water

10/1/98 water level on date shown

water inflow

partial drill fluid loss

complete drill fluid loss

25 water pressure test result (lugeons) for depth interval shown

weathering

FR	fresh
SW	slightly weathered
MW	moderately weathered
HW	highly weathered
XW	extremely weathered
DW	distinctly weathered (covers MW and HW)

strength

VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

defect type

JT	joint
PT	parting
SM	seam
SZ	sheared zone
SS	sheared surface
CS	crushed seam

roughness

VR	very rough
RO	rough
SO	smooth
SL	slickensided

planarity

PL	planar
CU	curved
UN	undulating
ST	stepped
IR	irregular

coating

CN	clean
SN	stained
VN	veneer
CO	coating

PROJECT FILE: GEOTKPAR01651AA_ONSHORE.GPJ. LIBRARY FILE: COFGEOTECHVER7REV3COLOUR.GLB. TEMPLATE FILE: COFFEY.GDT FRAME TITLE: CORED BOREHOLE. DATE: 17.2.11

Form GEO 5.5 Issue 3 Rev. 3

coffey geotechnics

Engineering Log - Borehole

Borehole No.	**BH17**
Sheet	1 of 2
Project No:	**GEOTKPAR01651AA**
Client:	**SHELL GLOBAL SOLUTIONS**
Principal:	**ARROW ENERGY**
Project:	**ARROW ENERGY LNG PROJECT**
Borehole Location:	**REFER TO DRG GEOTKPAR01651AA/0003**
Date started:	**1.8.2010**
Date completed:	**1.8.2010**
Logged by:	**CF**
Checked by:	**SG**

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	319438.53	slope:	-90°	R.L. Surface:	1.94
hole diameter:	100 mm	Northing	7368433.86	bearing:		datum:	AHD

drilling information / material substance

method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	classification symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	pocket penetro-meter kPa (100 200 300 400)	structure and additional observations
ADT		C					CH	**CLAY:** medium to high plasticity, brown/grey, with some organics.	M	S		TOPSOIL (MUD FLATS)
							CH	**SILTY CLAY:** high plasticity, dark grey, trace of fine grained sand and organics (wood material).	M/W	VS		MARINE DEPOSIT Auger falling under own weight
				U_{50}	1	1					×	DIST PP=10kPa 450MM RECOVERED
			08:40am	U_{50}							×	DIST PP=10kPa
					0	2			W			
RCB				U_{50}			CH	**SANDY CLAY:** high plasticity, brown/grey, fine to coarse grained sand.		S		U50 DISTURBED - 450MM RECOVERED
		N					CL	**GRAVELLY SANDY CLAY:** medium plasticity, brown/grey, fine to coarse grained sand, sub-angular to angular gravel. Some quartz.	M	F		ALLUVIUM
				SPT 3,2,4 N*=6	-1	3						450MM RECOVERED
							CH	**SANDY CLAY:** high plasticity, brown/grey, fine to coarse grained sand.				RESIDUAL SOIL
				U_{50}	-2	4				VSt		350MM RECOVERED
							CL	**SANDY CLAY:** medium plasticity, brown/grey, fine to coarse grained sand.			×	DIST PP=250kPa EXTREMELY WEATHERED SILTSTONE
				SPT 8,8,16 N*=24	-3	5						450MM RECOVERED
								...iron staining decreasing				
					-4	6						

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit

*bit shown by suffix
e.g. ADT

support

M mud N nil
C casing

penetration

1 2 3 4
no resistance ranging to refusal

water

▼ 10/1/98 water level on date shown
► water inflow
◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Borehole

Borehole No.	***BH17***
Sheet	2 of 2
Project No:	***GEOTKPAR01651AA***
Client:	***SHELL GLOBAL SOLUTIONS***
Principal:	***ARROW ENERGY***
Project:	***ARROW ENERGY LNG PROJECT***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***
Date started:	***1.8.2010***
Date completed:	***1.8.2010***
Logged by:	***CF***
Checked by:	***SG***

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	319438.53	slope:	-90°	R.L. Surface:	1.94
hole diameter:	100 mm	Northing	7368433.86	bearing:		datum:	AHD

drilling information							material substance						
method	penetration 1 2 3	support	water	**notes** samples, tests, etc	RL	depth metres	graphic log	classification symbol	**material** soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	**structure and additional observations**
RCB		N		SPT 16,12,20/140 N*=R				ML	**SANDY SILT:** low to medium plasticity, grey/brown, medium to coarse grained sand, trace of fine grained sub-angular gravel and iron staining.	M	H		SPT - 20 blows/140mm, 290MM RECOVERED
				SPT 21,20/130 N*=R	-5	7							SPT - 20 blows/130mm, 280MM RECOVERED
				SPT 20/90 N=R	-6	8			...with some fine grained angular gravel of siltstone - very low strength.				SPT - 20 blows/90mm - hammer bouncing, NO SAMPLE RECOVERED
					-7	9			**SILTSTONE:** fine grained, grey/orange/pale brown, distinctly bedded, highly weathered, very low strength.				HIGHLY WEATHERED SILTSTONE SPT - 5 blows/0mm - hammer bouncing
				SPT 5/0 N=R	-8	10			Borehole BH17 terminated at 10m				SPT at 10m - 5 blows/0mm - hammer bouncing, NO SAMPLE RECOVERED
					-9	11							
					-10	12							

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit
*bit shown by suffix	
e.g.	ADT

support

M mud N nil

C casing

penetration

1 2 3 4 no resistance ranging to refusal

water

10/1/98 water level on date shown

water inflow

water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description

based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Borehole

Borehole No.	**BH21**
Sheet	1 of 4
Project No:	**GEOTKPAR01651AA**
Client:	**SHELL GLOBAL SOLUTIONS**
Principal:	**ARROW ENERGY**
Project:	**ARROW ENERGY LNG PROJECT**
Borehole Location:	**REFER TO DRG GEOTKPAR01651AA/0003**
Date started:	**13.7.2010**
Date completed:	**14.7.2010**
Logged by:	**CF**
Checked by:	**SG**

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	317933.47	slope:	-90°	R.L. Surface:	2.76
hole diameter:	100 mm	Northing	7368125.07	bearing:		datum:	AHD

drilling information / material substance

method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	classification symbol	material: soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetrometer kPa 100 200 300 400	structure and additional observations
ADT		C		D			CL	**SANDY CLAY:** low plasticity, brown, fine to medium grained sand, with some fine grained angular gravel and some organics (rootlets).	D	S		TOPSOIL
				D			SC	**GRAVELLY CLAYEY SAND:** fine to coarse grained, brown, medium plasticity fines, fine to medium grained sub-angular quartz and chert gravel, trace of rootlets.		F		ALLUVIUM
				SPT 6,9,10 N*=19	2							
				SPT 5,5,4 N*=9		1						
							CL	**SANDY CLAY:** medium plasticity, brown/red, fine to coarse grained sand, with some fine grained angular gravel of quartz and trace of organics (rootlets).	M			
			13:40pm		1	2						
				SPT 6,3,3 N*=6				...with grey mottling.				
		N									×	DIST PP=70kPa
					0	3						
RCB				SPT 6,6,9 N*=15			CH	**SANDY CLAY:** high plasticity, grey/dark red, fine grained sand. Trace of fine grained quartz.		St	×	DIST PP=320KPa RESIDUAL SOIL
											×	DIST PP=340kPa
					-1	4						
				U_{50}							×	150mm recovered DIST PP>400kPa
							CH	**CLAY:** high plasticity, dark red/grey, with some fine to coarse grained sand, trace of fine grained angular gravel.				
					-2	5						
				SPT 12,12,21 N*=33					D	H		SPT bouncing for last 50mm
					-3	6						

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit

*bit shown by suffix
e.g. ADT

support

M	mud	N	nil
C	casing		

penetration
1 2 3 4
no resistance ranging to refusal

water

10/1/98 water level on date shown
water inflow
water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Borehole

Borehole No.	***BH21***
Sheet	2 of 4
Project No:	***GEOTKPAR01651AA***
Client:	***SHELL GLOBAL SOLUTIONS***
Principal:	***ARROW ENERGY***
Project:	***ARROW ENERGY LNG PROJECT***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***
Date started:	***13.7.2010***
Date completed:	***14.7.2010***
Logged by:	***CF***
Checked by:	***SG***

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	317933.47	slope:	-90°	R.L. Surface:	2.76
hole diameter:	100 mm	Northing	7368125.07	bearing:		datum:	AHD

drilling information | **material substance**

method	penetration 1 2 3	support	water	**notes** samples, tests, etc	RL	depth metres	graphic log	classification symbol	**material** soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	**structure and additional observations**
RCB		N		SPT 10,17,21 N*=38				CH	**CLAY:** high plasticity, dark red/grey, with some fine to coarse grained sand, trace of fine grained angular gravel. *(continued)*	D	H		
					-4								
						7			...with trace of fine grained red angular gravel, with red mottling.				
				SPT 7,24,25/140 N*=R				CL	**SILTY CLAY:** medium plasticity, grey, contains laminations, trace of medium to coarse grained sand and fine grained red angular gravel.				EXTREMELY WEATHERED SILTSTONE SPT - 25 blows/140mm - hammer bouncing
					-5				...with yellow/red mottling.				
				SPT 11,21/110 N*=R		8							
									SILTSTONE: grey, indistinctly laminated, highly weathered, medium strength.				SPT - 21 blows/110mm - hammer bouncing HIGHLY WEATHERED SILTSTONE
								CL	**SILTY CLAY:** low to medium plasticity, grey, trace of medium to coarse grained sand and fine grained red angular gravel with some red/yellow mottling.	D	H		EXTREMELY WEATHERED SILTSTONE
					-6								
				SPT 12,19,26 N*=45		9			...some yellow/orange iron staining along laminations.				
					-7								
				SPT 11,10,25 N*=35		10							
					-8								
				SPT 12,20,27 N*=47		11			...with fine grained gravel, angular, grey (highly weathered siltstone).				
					-9								
						12							

method

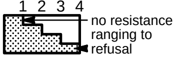
AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit

*bit shown by suffix
e.g. ADT

support

M mud N nil
C casing

penetration



water

▼ 10/1/98 water level on date shown
► water inflow
◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Borehole

Borehole No.	***BH21***
Sheet	3 of 4
Project No:	***GEOTKPAR01651AA***
Client:	***SHELL GLOBAL SOLUTIONS***
Date started:	***13.7.2010***
Principal:	***ARROW ENERGY***
Date completed:	***14.7.2010***
Project:	***ARROW ENERGY LNG PROJECT***
Logged by:	***CF***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***
Checked by:	***SG***

drill model and mounting:	HYDRAPOWER SCOUT	Easting:	317933.47	slope:	-90°	R.L. Surface:	2.76
hole diameter:	100 mm	Northing	7368125.07	bearing:		datum:	AHD

drilling information | **material substance**

method	penetration 1 2 3	support	water	**notes** samples, tests, etc	RL	depth metres	graphic log	classification symbol	**material** soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	**structure and additional observations**
RCB		N		SPT 11,22,28/140 N*=R				CL	**SILTY CLAY:** low to medium plasticity, grey, trace of medium to coarse grained sand and fine grained red angular gravel with some red/yellow mottling. *(continued)* ...with orange iron staining along laminations.	D	H		SPT - 28 blows/140mm - hammer bouncing
					-10								
						13			...with some coarse grained sand and fine grained angular gravel of siltstone.				
				SPT 10,21,24 N*=45									
					-11								
						14							
				SPT 20,28,28/100 N*=R									SPT - 28 blows/100mm - hammer bouncing
					-12								
						15							
				SPT 22,12/70 N*=R				CL	**GRAVELLY SILTY CLAY:** low to medium plasticity, pale brown, fine grained angular siltstone gravel with some medium to coarse grained sand and iron staining on laminations and gravel fragments.				SPT - 12 blows/70mm - hammer bouncing
					-13								
						16							
				SPT 16/90 N*=R	-14								SPT - 16 blows/90mm - hammer bouncing
						17							
					-15								
						18							

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit

*bit shown by suffix
e.g. ADT

support

M	mud	N	nil
C	casing		

penetration
1 2 3 4
no resistance ranging to refusal

water

10/1/98 water level on date shown
water inflow
water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Borehole

Borehole No. **BH21**
Sheet 4 of 4
Project No: **GEOTKPAR01651AA**

Client: **SHELL GLOBAL SOLUTIONS**
Principal: **ARROW ENERGY**
Project: **ARROW ENERGY LNG PROJECT**
Borehole Location: **REFER TO DRG GEOTKPAR01651AA/0003**

Date started: **13.7.2010**
Date completed: **14.7.2010**
Logged by: **CF**
Checked by: **SG**

drill model and mounting: HYDRAPOWER SCOUT
Easting: 317933.47
slope: -90°
R.L. Surface: 2.76
hole diameter: 100 mm
Northing 7368125.07
bearing:
datum: AHD

drilling information							material substance						
method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	pocket penetro-meter kPa 100 200 300 400	structure and additional observations
RCB	▨	N		SPT 14/80 N*=R SPT 26/130 N*=R	-16 -17	19	▨	CL	**GRAVELLY SILTY CLAY:** low to medium plasticity, pale brown, fine grained angular siltstone gravel with some medium to coarse grained sand and iron staining on laminations and gravel fragments. *(continued)*	D	H		SPT - 14 blows/80mm - hammer bouncing SPT - 26 blows/130mm - hammer bouncing
					-17 -18 -19 -20 -21	20 21 22 23 24			Borehole BH21 terminated at 19.63m				

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube
B	blank bit
V	V bit
T	TC bit
*bit shown by suffix	
e.g.	ADT

support

M	mud	N	nil
C	casing		

penetration
1 2 3 4
no resistance ranging to refusal

water
▼ 10/1/98 water level on date shown
► water inflow
◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
U_{63}	undisturbed sample 63mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
V	vane shear (kPa)
P	pressuremeter
Bs	bulk sample
E	environmental sample
R	refusal

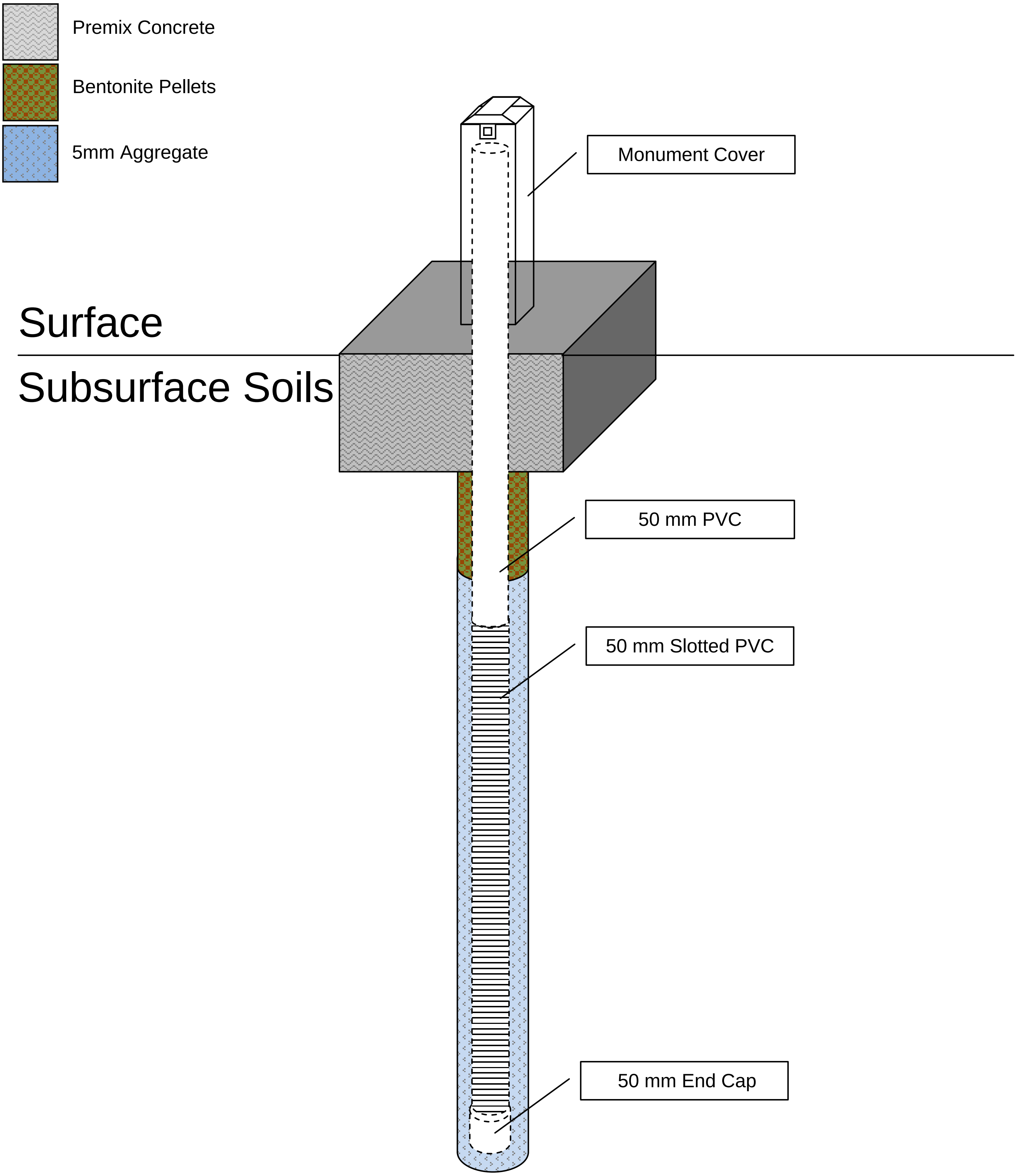
classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense



drawn	**RY**	client:	**Shell Global Solutions (SGSMY)**
approved	**SG**	project:	**Arrow Energy LNG Project** **Preliminary Geotechnical Investigation** **Onshore LNG Facility, Curtis Island**
date	**25.01.11**		
scale	**NTS**	title:	**Typical Sketch of Standpipe Piezometer**
original size	**A4**	project no: **GEOTKPAR01651AA**	**Appendix J**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

coffey geotechnics

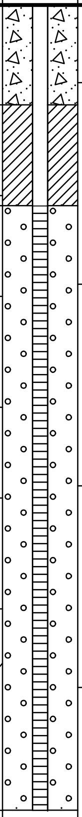
Borehole No.	**BH02**
Sheet	1 of 2
Project No:	**GEOTKPAR01651AA**

Engineering Log - Piezometer

Client:	***SHELL GLOBAL SOLUTIONS***	Date started:	***20.7.2010***
Principal:	***ARROW ENERGY***	Date completed:	***20.7.2010***
Project:	***ARROW ENERGY LNG PROJECT***	Logged by:	***CF***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***	Checked by:	***SG***

drill model & mounting:HYDRAPOWER SCOUT	Easting: 319275.09	slope: -90°	R.L. Surface: 24.39
hole diameter:	Northing: 7369846.39	bearing:	datum: AHD

drilling information / **material substance**



method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	structure and additional observations
ADT		C	NONE OBSERVED				ML	**SANDY SILT:** Low liquid limit, brown, fine to medium grained, with some fine grained sub-angular gravel, with some rootlets.	D	F	TOPSOIL
					24		CL	**GRAVELLY SANDY CLAY:** Low plasticity, brown, fine grained sand, fine to coarse grained angular gravel, trace of rootlets. ... Low plasticity, brown-orange, fine to medium grained sand, fine to medium grained angular gravel of siltstone.		F-St	RESIDUAL SOIL
				SPT 6,14,14 N*=28						VSt-H	
						1					DIST PP>=400kPa
				SPT 7,16,12 N*=28	23		CH	**SANDY CLAY:** Medium to high plasticity, grey-brown, fine to coarse grained sand, with some fine grained sub-angular gravel.			DIST PP>=400kPa
						2					
				SPT 4,7,7 N*=14	22						
RCB						3	GC	**GRAVELLY CLAY:** Medium to high plasticity, brown, red, grey, fine grained angular gravel, with some medium to coarse grained sand. Gravel includes siltstone, chert and quartz fragments.			
				SPT 27,18/120 N*=R	21						SPT - Hammer bouncing, 18 blows for 120mm
						4	CH	**CLAY:** Medium to high plasticity, pale brown/ orange, with some laminations and with some medium to coarse grained sand.			EXTREMELY WEATHERED SILTSTONE
				SPT 13,10,12 N*=22	20						
						5				H	
				SPT 13 N*=R	19						SPT - Hammer bouncing, 30 blows for 140mm
						6					

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
DT	diatube
B	blank bit
V	V bit
T	TC bit
TBX	Tubex

*bit shown by suffix
e.g. ADT

support

C casing N nil

penetration

1 2 3 4 no resistance ranging to refusal

water

▼ 10/1/98 water level on date shown

► water inflow

◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
P	pressure meter
Bs	bulk sample
R	refusal
E	environmental sample
PID	PID measurement
WS	water sample
PZ	piezometer
ALT	air lift test

classification symbols and soil description

based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Borehole No. **BH12**

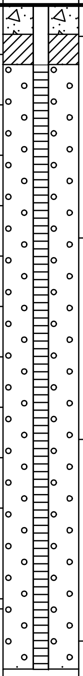
Sheet 1 of 2

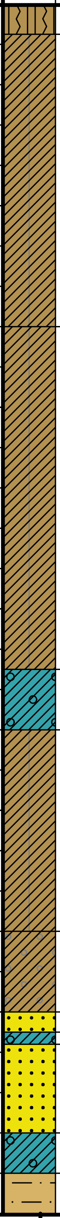
Engineering Log - Piezometer

Client:	*SHELL GLOBAL SOLUTIONS*	Project No:	*GEOTKPAR01651AA*
Principal:	*ARROW ENERGY*	Date started:	*2.8.2010*
Project:	*ARROW ENERGY LNG PROJECT*	Date completed:	*3.8.2010*
Borehole Location:	*REFER TO DRG GEOTKPAR01651AA/0003*	Logged by:	*CF*
		Checked by:	*SG*

drill model & mounting:HYDRAPOWER SCOUT	Easting: 320238.76	slope: -90°	R.L. Surface: 2.16
hole diameter:	Northing: 7369118.22	bearing:	datum: AHD

drilling information | **material substance**





depth metres	RL	method	penetration 1 2 3	support	water	notes samples, tests, etc	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	structure and additional observations
0.0	2	ADT		C		ASS	CL	**SILTY CLAY:** low to medium plasticity, brown, some fine grained sand, trace of organics.	D/M	F	TOPSOIL (MUD FLATS)
						ASS U$_{50}$ ASS	CH	**SILTY CLAY:** high plasticity, brown/pale brown, trace of fine grained sand, some organics.	M	VS	MARINE DEPOSIT ASS samples taken at 0.25m intervals between 0.0 - 3.5m 450mm recovered
1	1				2:20pm	U$_{50}$ ASS		...colour changing to grey/blue.	W		PP=10kPa 450mm recovered
						U$_{50}$				F	ALLUVIUM PP=80kPa 450mm recovered
						ASS	CL	**SILTY CLAY:** medium plasticity, grey/blue, trace of fine grained sand, some organics.			
2	0	RCB				U$_{50}$		...colour changing to grey/brown.	M	VSt	PP=250kPa 450mm recovered
				M		ASS		... gravel layer 2.3 to 2.5m - fine grained sub-angular.			
						SPT 3,7,9 N*=16		...with some fine to medium grained sand.			PP=300kPa 450mm recovered PP>400kPa
3	-1					SPT 2,10,23 N*=33					450mm recovered
							GC	**CLAYEY GRAVEL:** fine to medium grained angular to subangular, brown/grey/red, medium plasticity clay.		D	
							CL	**SILTY CLAY:** medium plasticity, grey/brown, with some fine to medium grained sand, trace of fine grained angular gravel.		VSt	RESIDUAL SOIL
4	-2					SPT 3,9,10 N*=19		...iron staining and cement visable on siltstone fragments.			EXTREMELY WEATHERED SILTSTONE/SANDSTONE 450mm recovered
							CL	**GRAVELLY CLAY:** medium to low plasticity, orange/grey, fine grained angular siltstone gravel.		H	PP=400kPa
5	-3	NMLC						**SANDSTONE:** fine grained, pale brown, indistinctly bedded, with some iron staining of relict fractures, bleaching along open defects.			
								CLAYEY GRAVEL (GC): fine grained, brown, sub-angular to angular, low plasticity clay.			
								SANDSTONE: fine grained, pale brown, indistinctly bedded, with some iron staining of relict fractures, bleaching along open defects.			
6								**CLAYEY GRAVEL (GC):** fine grained, brown, sub-angular to angular, low plasticity clay.			

method		support		notes, samples, tests		consistency/density index	
AS	auger screwing*	C casing	N nil	U$_{50}$	undisturbed sample 50mm diameter	VS	very soft
AD	auger drilling*			D	disturbed sample	S	soft
RR	roller/tricone	**penetration**		N	standard penetration test (SPT)	F	firm
W	washbore	1 2 3 4		N*	SPT - sample recovered	St	stiff
CT	cable tool	no resistance ranging to refusal		Nc	SPT with solid cone	VSt	very stiff
DT	diatube			P	pressure meter	H	hard
B	blank bit	**water**		Bs	bulk sample	Fb	friable
V	V bit	▼ 10/1/98 water level on date shown		R	refusal	VL	very loose
T	TC bit			E	environmental sample	L	loose
TBX	Tubex			PID	PID measurement	MD	medium dense
*bit shown by suffix		► water inflow		WS	water sample	D	dense
e.g.	ADT	◄ water outflow		PZ	piezometer	VD	very dense
				ALT	air lift test		

classification symbols and soil description
based on unified classification system

moisture	
D	dry
M	moist
W	wet
Wp	plastic limit
W$_L$	liquid limit

PROJECT FILE: GEOTKPAR01651AA_ONSHORE.GPJ. LIBRARY FILE: COFGEOTECHVER7REV3COLOUR.GLB. TEMPLATE FILE: COFFEY.GDT FRAME TITLE: PIEZOMETER. DATE: 30.5.11

Form GEO 5.10 Issue 3 Rev.0

coffey geotechnics

Engineering Log - Piezometer

Borehole No.	***BH16***
Sheet	1 of 4
Project No:	***GEOTKPAR01651AA***

Client:	***SHELL GLOBAL SOLUTIONS***	Date started:	***30.7.2010***
Principal:	***ARROW ENERGY***	Date completed:	***31.7.2010***
Project:	***ARROW ENERGY LNG PROJECT***	Logged by:	***SH***
Borehole Location:	***REFER TO DRG GEOTKPAR01651AA/0003***	Checked by:	***SG***

drill model & mounting: HYDRAPOWER SCOUT	Easting: 319783.84	slope: -90°	R.L. Surface: 3.30
hole diameter:	Northing: 7368646.48	bearing:	datum: AHD

drilling information | **material substance**

method	support	water	notes samples, tests, etc	classification symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	structure and additional observations
ADT	C	NONE OBSERVED		CH	**CLAY:** high plasticity, brown, trace of fine to coarse grained sand and fine grained gravel.	D	St	TOPSOIL
			SPT 5,5,4 N*=9	CH	**SILTY CLAY:** high plasticity, brown, trace of fine to coarse grained sand.	M		ALLUVIUM
			SPT 2,3,4 N*=7 SPT 2,4,13 N*=17	CL	**GRAVELLY SILTY CLAY:** low to medium plasticity, brown with red/orange mottling, fine grained sub-angular gravel.		VSt	RESIDUAL DIST PP=280kPa
			U₅₀	CL	**SILTY CLAY:** low plasticity, grey and orange mottled, trace of fine to medium grained sand.			
RCB			SPT 9,12,26 N*=38 SPT 18,25,16 N*=41	GP	**CLAYEY SANDY GRAVEL:** fine to medium grained, brown/red, fine to coarse grained sand, medium plasticity clay fines.		VD	PP=260kPa

penetration 1 2 3 | well details | RL: 3, 2, 1, 0, -1, -2 | depth metres: 1, 2, 3, 4, 5, 6 | graphic log

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
DT	diatube
B	blank bit
V	V bit
T	TC bit
TBX	Tubex

*bit shown by suffix
e.g. ADT

support
C casing N nil

penetration
1 2 3 4
no resistance ranging to refusal

water
▼ 10/1/98 water level on date shown
► water inflow
◄ water outflow

notes, samples, tests

U$_{50}$	undisturbed sample 50mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
P	pressure meter
Bs	bulk sample
R	refusal
E	environmental sample
PID	PID measurement
WS	water sample
PZ	piezometer
ALT	air lift test

classification symbols and soil description
based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W$_L$	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

coffey geotechnics

Engineering Log - Piezometer

Borehole No. **BH17**

Sheet 1 of 2

Project No: **GEOTKPAR01651AA**

Client: **SHELL GLOBAL SOLUTIONS**

Principal: **ARROW ENERGY**

Project: **ARROW ENERGY LNG PROJECT**

Borehole Location: **REFER TO DRG GEOTKPAR01651AA/0003**

Date started: **1.8.2010**

Date completed: **1.8.2010**

Logged by: **CF**

Checked by: **SG**

drill model & mounting: HYDRAPOWER SCOUT

Easting: 319438.53

slope: -90°

R.L. Surface: 1.94

hole diameter:

Northing: 7368433.86

bearing:

datum: AHD

drilling information

material substance

method	penetration 1 2 3	support	water	notes samples, tests, etc	well details	RL	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	structure and additional observations
ADT		C							CH	**CLAY:** medium to high plasticity, brown/grey, with some organics.	M	S	TOPSOIL (MUD FLATS)
									CH	**SILTY CLAY:** high plasticity, dark grey, trace of fine grained sand and organics (wood material).	M/W	VS	MARINE DEPOSIT Auger falling under own weight
				U50		1	1						DIST PP=10kPa 450MM RECOVERED
			08:40am	U50									DIST PP=10kPa
											W		
RCB				U50		0	2						U50 DISTURBED - 450MM RECOVERED
									CH	**SANDY CLAY:** high plasticity, brown/grey, fine to coarse grained sand.		S	
		N											
									CL	**GRAVELLY SANDY CLAY:** medium plasticity, brown/grey, fine to coarse grained sand, sub-angular to angular gravel. Some quartz.	M	F	ALLUVIUM
				SPT 3,2,4 N*=6		-1	3						450MM RECOVERED
									CH	**SANDY CLAY:** high plasticity, brown/grey, fine to coarse grained sand.			RESIDUAL SOIL
				U50		-2	4					VSt	350MM RECOVERED
													DIST PP=250kPa
									CL	**SANDY CLAY:** medium plasticity, brown/grey, fine to coarse grained sand.			EXTREMELY WEATHERED SILTSTONE
				SPT 8,8,16 N*=24		-3	5						450MM RECOVERED
										...iron staining decreasing			
						-4	6						

method

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
DT	diatube
B	blank bit
V	V bit
T	TC bit
TBX	Tubex

*bit shown by suffix
e.g. ADT

support

C casing N nil

penetration

1 2 3 4 no resistance ranging to refusal

water

▼ 10/1/98 water level on date shown

► water inflow

◄ water outflow

notes, samples, tests

U_{50}	undisturbed sample 50mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
P	pressure meter
Bs	bulk sample
R	refusal
E	environmental sample
PID	PID measurement
WS	water sample
PZ	piezometer
ALT	air lift test

classification symbols and soil description

based on unified classification system

moisture

D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

PROJECT FILE: GEOTKPAR01651AA_ONSHORE.GPJ. LIBRARY FILE: COFGEOTECHVER7REV3COLOUR.GLB. TEMPLATE FILE: COFFEY.GDT FRAME TITLE: PIEZOMETER. DATE: 30.5.11

coffey geotechnics

Engineering Log - Piezometer

Borehole No. **BH21**

Sheet 1 of 4

Project No: **GEOTKPAR01651AA**

Client: **SHELL GLOBAL SOLUTIONS**

Principal: **ARROW ENERGY**

Project: **ARROW ENERGY LNG PROJECT**

Borehole Location: **REFER TO DRG GEOTKPAR01651AA/0003**

Date started: **13.7.2010**

Date completed: **14.7.2010**

Logged by: **CF**

Checked by: **SG**

drill model & mounting: HYDRAPOWER SCOUT

Easting: 317933.47

slope: -90°

R.L. Surface: 2.76

hole diameter:

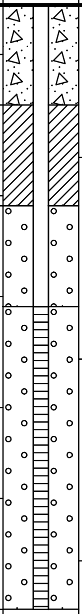
Northing: 7368125.07

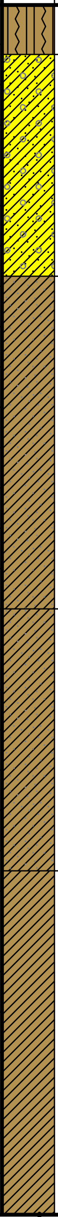
bearing:

datum: AHD

drilling information

material substance





method	penetration 1 2 3	support	water	notes samples, tests, etc	RL	depth metres	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	structure and additional observations
ADT		C		D			CL	**SANDY CLAY:** low plasticity, brown, fine to medium grained sand, with some fine grained angular gravel and some organics (rootlets).	D	S	TOPSOIL
				D			SC	**GRAVELLY CLAYEY SAND:** fine to coarse grained, brown, medium plasticity fines, fine to medium grained sub-angular quartz and chert gravel, trace of rootlets.		F	ALLUVIUM
				SPT 6,9,10 N*=19	2						
				SPT 5,5,4 N*=9		1					
							CL	**SANDY CLAY:** medium plasticity, brown/red, fine to coarse grained sand, with some fine grained angular gravel of quartz and trace of organics (rootlets).	M		
			13:40pm		1						
				SPT 6,3,3 N*=6		2		...with grey mottling.			
		N									DIST PP=70kPa
					0	3					
RCB				SPT 6,6,9 N*=15			CH	**SANDY CLAY:** high plasticity, grey/dark red, fine grained sand. Trace of fine grained quartz.		St	DIST PP=320KPa RESIDUAL SOIL
											DIST PP=340kPa
					-1	4					
				U_{50}							150mm recovered DIST PP>400kPa
							CH	**CLAY:** high plasticity, dark red/grey, with some fine to coarse grained sand, trace of fine grained angular gravel.			
					-2	5					
				SPT 12,12,21 N*=33					D	H	SPT bouncing for last 50mm
					-3	6					

method	
AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
DT	diatube
B	blank bit
V	V bit
T	TC bit
TBX	Tubex
*bit shown by suffix	
e.g.	ADT

support

C casing N nil

penetration

1 2 3 4 – no resistance ranging to refusal

water

▼ 10/1/98 water level on date shown

► water inflow

◄ water outflow

notes, samples, tests	
U_{50}	undisturbed sample 50mm diameter
D	disturbed sample
N	standard penetration test (SPT)
N*	SPT - sample recovered
Nc	SPT with solid cone
P	pressure meter
Bs	bulk sample
R	refusal
E	environmental sample
PID	PID measurement
WS	water sample
PZ	piezometer
ALT	air lift test

classification symbols and soil description

based on unified classification system

moisture	
D	dry
M	moist
W	wet
Wp	plastic limit
W_L	liquid limit

consistency/density index	
VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

PROJECT FILE: GEOTKPAR01651AA_ONSHORE.GPJ. LIBRARY FILE: COFFGEOTECHVER7REV3COLOUR.GLB. TEMPLATE FILE: COFFEY.GDT FRAME TITLE: PIEZOMETER. DATE: 30.5.11

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Appendix B

DERM registered bores used in the groundwater desk study

Borehole Registration Number	Source location		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(L/s)	(mg/L)	Unit
88336	307326	7362612	7.9	granite	TARGINIE GRANITE	4.6	7.9	-4.6	1.3	124.4	6.4
88143	309292	7361571	16	Weathered volcanic rock	DOONSIDE FORMATION	10	15.8	-3.5	3.9	potable	ND
136123	321684	7360017	17.1	Silty gravel	ND	13	-	-11.1	1	potable	ND
88587	307705	7359317	32	Weathered granite	TARGINIE GRANITE	22.9	28.1	-22.6	0.75	potable	ND
91788	307328	7367509	19	Decomposed granite	TARGINIE GRANITE	11	19	-10	0.26	potable	ND
84298	304075	7370268	32	granite	TARGINIE GRANITE	27.5		-21	ND	343	5.3
88335	307425	7362184	30.5	Weathered granite	TARGINIE GRANITE	18.9	24.1	-11.6	1.1	406.6	6.5
111773	317739	7357877	22	chert	WANDILLA FORMATION	17	ND	-10	0.75	469	ND

Notes:
Data from Department of the Environment and Resource Management (DERM) registered bore database (accessed 2010)
ND: no data/record
mbgl: metres below ground level

drawn	**KOS/MN**
approved	
date	**06/2010**
scale	**-**
original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell Australia Liquefied Natural Gas EIS Groundwater Desk Study**

title: Registered bores compiled from the DNRW Groundwater Database showing estimated yield of <5L/s and a salinity of <500mg/L

project no: NSYSBRIS07033BB

Table no: **B1**

Borehole Registration Number	Source location		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(L/s)	(mg/L)	Unit
88340	312507	7356395	30	chert	ND	ND	ND	ND	0.5	936.7	8.1
88459	306884	7367335	15.2	Decomposed granite	Hand dug old town well; Irrigation of small crops	ND	ND	5.9	ND	838.7	6
91185	315805	7355212	48.3	ND	ND	ND	ND	ND	ND	785	6.9
91986	315823	7354343	23	Fresh chert	DOONSIDE FORMATION	15	20	-6	3.7	536	ND
97440	311406	7366735	23	Fresh fractured shale	WANDILLA FORMATION	17	23	-10	3	603	ND
97693	300058	7368257	14.6	Weathered andesite	BERSERKER BEDS	9.4	19	ND	2.02	1005	ND
122793	294581	7366258	34	mudstone	ROCKHAMPTON GROUP	23	34	-18	1.51	894.45	ND
122111	317176	7353991	10	chert	DOONSIDE FORMATION	8	11	ND	0.82	569.5	ND
111731	322272	7356834	34	shale	WANDILLA FORMATION	27	32	-25	0.76	603	ND
111793	322293	7356843	34	mudstone	WANDILLA FORMATION	27	32	-25	0.75	603	ND
88324	317300	7351570	17.7	Decomposed slate	DOONSIDE FORMATION	7.9	12.2	-10.3	0.5	837.5	7.1
88337	304248	7370926	-	granite	TARGINIE GRANITE	18.3	-	-6.1	0.5	897.8	8.1
111423	308071	7365576	24.99	Decomposed granite	GRANITE	19.51	22.56	-15.24	0.45	737	ND
88456	306937	7367668	23.2	Weathered granite	TARGINIE GRANITE	14	22.6	-15	0.35	922.59	8.4
122113	315813	7354405	30	chert	DOONSIDE FORMATION	19	23	-12	0.25	804	ND
122112	317237	7355838	33	chert	WANDILLA FORMATION	22	30	-19	0.19	721.59	ND
91789	307545	7365176	20	Decomposed granite	TARGINIE GRANITE	10	20	-6	2.6	737	ND
122949	310780	7364287	24	chert	DOONSIDE FORMATION	18	24	-6.7	2.5	837.5	ND
122816	316323	7354319	24.5	Fractured chert	DOONSIDE FORMATION	18	24.5	-9	1.89	737	ND

Notes:
Data from Department of the Environment and Resource Management (DERM) registered bore database (accessed 2010)
ND: no data/record
mbgl: metres below ground level

drawn	**KOS/MN**
approved	
date	**06/2010**
scale	**-**
original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell Australia Liquefied Natural Gas EIS Groundwater Desk Study**

title: Registered bores compiled from the DNRW Groundwater Database showing estimated yield of <5L/s and a salinity of 500-1500 mg/L

project no: NSYSBRIS07033BB

Table no: **B2**

Borehole Registration Number	Bore coordinates		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(L/s)	(mg/L)	
136873	322418	7355503	28.8	mudstone	CURTIS ISLAND GROUP	18	28.8	-12.6	1.89	670	ND
122831	312333	7354421	24	Sedimentary rock	DOONSIDE FORMATION	12	17	-10	1.51	938	ND
111800	321390	7357467	12	mudstone	WANDILLA FORMATION	5.7	12	-5.5	1.26	603	ND
136597	316025	7353130	30	ND	ND	19	20.7	-15	1.26	603	ND
122835	316323	7354319	24.5	Sedimentary rock	DOONSIDE FORMATION	18	24.5	-9	1.19	737	ND
122615	294573	7363116	25	basalt	ROCKHAMPTON GROUP	16	ND	-14	0.51	790.6	ND
122649	318448	7354069	25	granite	WANDILLA FORMATION	14	ND	-12	0.38	924.6	ND
122650	312210	7353066	46	granite	CALLIOPE BEDS	37	46	-20	0.15	603	ND
151058	309156	7361549	17.5	Tuff, mudstone	BERSERKER BEDS	15	ND	-6.4	0	2546	ND
122619	293633	7364413	43	basalt		40	ND	20	0.25	938	ND
97677	299702	7368873	6.1	ND	ND	ND	ND	-1.3	ND	1352	7.9
97254	311587	7355363	18.3	volcanic	CALLIOPE BEDS	14.33	18.29	-5.49	3.16	1166	7.2
111583	310410	7358844	22.5	granite	DOONSIDE FORMATION	17	22.5	-16.4	2.7	871	ND
111796	321908	7356983	23	mudstone	WANDILLA FORMATION	18	20	-13.2	2.27	1206	ND
111604	311673	7354812	18.29	Serpentine, volcanic	CALLIOPE BEDS	12.19	15.85	-9.14	1.77	1340	ND
97960	308122	7365684	18	granite	TARGINIE GRANITE	13.7	ND	ND	1.26	1206	ND
88338	312438	7363279	23.8	granite	DOONSIDE FORMATION	22	23.8	-11.2	1	1221	7.1
111799	316263	7355011	30	chert	DOONSIDE FORMATION	24	30	-20	0.88	1340	ND
97892	311682	7355240	18.52	Weathered&jointed andesite	CALLIOPE BEDS	14.8	ND	-9	0.82	1206	ND

Notes:
Data from Department of the Environment and Resource Management (DERM) registered bore database (accessed 2010)
ND: no data/record
mbgl: metres below ground level

drawn	**KOS/MN**
approved	
date	**29/04/2010**
scale	**-**
original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell LNG EIS GW Study**

title: Registered bores compiled from the DNRW Ground water Database showing a yield of <5L/s and a salinity of 500-1500mg/L

project no: NSYSBRIS0703BB

Table no: **B2**

Borehole Registration Number	Bore coordinates		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(L/s)	(mg/L)	
97989	307799	7365825	23	Weathered granite	TARGINIE GRANITE	13	ND	-11	0.76	1273	ND
111797	321535	7361621	19	mudstone	WANDILLA FORMATION	17	19	-9	0.75	1340	ND
111804	320772	7358059	7	Medium-large creek gravel	AUCKLAND CREEK ALLUVIUM	5	9	ND	0.75	1340	ND
88344	299881	7372165	16.1	volcanic	BERSERKER BEDS	10	16.1	-10.9	0.6	1397	7.9
111378	307350	7364283	21.34	Decomposed granite	GRANITE	17.37	17.98	-9.14	0.38	1072	ND
84294	304063	7371948	13.7	diorite	BERSERKER BEDS	4	13	-4.45	0.2	1072	ND
97678	298013	7368733	30.5	andesite	BERSERKER BEDS	12.2	13.7	-10.7	0.12	979	7.4
111120	307428	7367308	36.5	granite	TARGINIE GRANITE	18.9	ND	-15.24	0.08	1072	ND
136402	317580	7352327	30	Fractured mudstone	CURTIS ISLAND GROUP	18	22.8	-16.7	0.38	1474	ND
136598	316088	7353360	36.5	ND	ND	24	27.4	-15	0.63	1340	ND
136517	309079	7361720	21.3	Weathered rock	BERSERKER BEDS	17	17.6	-8.5	1.01	1407	ND
136514	309130	7361248	21.3	Decomposed rock	BERSERKER BEDS	16.7	17	-21	1.26	1340	ND
111744	321921	7357067	25	chert	WANDILLA FORMATION	21.3	25	-10.7	1.5	1340	ND
122097	322887	7361139	17	chert	WANDILLA FORMATION	6	17	-4	1.51	838	ND
122648	321357	7356659	19	granite	WANDILLA FORMATION	12	19	-5	2.27	1474	ND
122842	307937	7359563	19	granite	TARGINIE GRANITE	10	19	-10	2.27	1072	ND
91795	307728	7364973	18	Decomposed granite	TARGINIE GRANITE	9	18	-4	5.7	636.5	ND

Note; Light green refers to a yield of <5L/s
Dark green refers to a yield between 5L/s and 15L/s (Registered groundwater bore 91795)

Notes:
Data from Department of the Environment and Resource Management (DERM) registered bore database (accessed 2010)
ND: no data/record
mbgl: metres below ground level

drawn	**KOS/MN**
approved	
date	**29/04/2010**
scale	**-**
original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell LNG EIS GW Study**

title: Registered bores compiled from the DNRW Ground water Database showing a yield of <5L/s and a salinity of 500-1500mg/L

project no: NSYSBRIS0703BB

Table no: **B2**

Borehole Registration Number	Bore coordinates		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(L/s)	(mg/L)	
91186	316254	7355198	43	ND	ND	ND	ND	ND	ND	2881	8.5
97442	303767	7370400	30.6	ND	ND	ND	ND	ND	0.88	2586.2	7.4
97443	303748	7370311	22.86	ND	ND	ND	ND	ND	0.78	1762.1	7.4
97444	306574	7370807	20.7	ND	ND	ND	ND	ND	0.73	2894.4	8
97489	304333	7371972	12.19	ND	ND	ND	ND	ND	ND	1929.6	7.3
122745	294386	7361254	19.8	Fractured sedimentary rocks	MOUNT ALMA FORMATION	12	19.8	-3	2.6	4770	ND
88341	308742	7362084	20	Fractured volcanic rock	BERSERKER BEDS	13	17	-5.42	4.4	3283	7.3
97818	311014	7353870	30	Weathered andesite	YARWUN BEDS	21.6	-	-9	3.78	2726.9	7.8
97959	309108	7361685	18.5	Decomposed granite	TARGINIE GRANITE	14.3	19	-6	3.15	2613	ND
97890	310405	7354408	18.5	Weathered andesite	YARWUN BEDS	16.3	-	-5.3	2.52	2546	ND
111786	324242	7356218	39	mudstone	WANDILLA FORMATION	36	37	-28	2.52	2010	ND
111795	307048	7356474	20	mudstone	CRANA BEDS	16	20	-10	2.52	2345	ND
111803	322666	7358869	28	mudstone	WANDILLA FORMATION	21	27	-18	2.26	1675	ND
67676	310143	7359789	15.2	Fractured mudstone	DOONSIDE FORMATION	9.2	15.3	-4	1.9	2631.1	7.6
91847	317566	7353808	30.5	Broken andesite	DOONSIDE FORMATION	17	29.2	-12	1.8	3082	ND
111438	309159	7361676	12.19	granite	BERSERKER BEDS	10.97	12.19	-2.44	1.77	2680	ND
111788	321139	7356903	16	Broken mudstone	WANDILLA FORMATION	12	13	-8	1.5	2144	ND
136407	309237	7361441	18	Fractured mudstone	YARROL BASIN SEQUENCE	15	16.7	-9	1.26	2278	ND
111789	320730	7355677	36	mudstone	WANDILLA FORMATION	33	36	-18	1	1675	ND

drawn	**KOS**
approved	
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original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell LNG EIS GW Study**

title: Registered bores compiled from the DNRW Ground water Database showing a yield of <5L/s and a salinity of 1500 - 5000mg/L

project no: NSYSBRIS07033BB

Table no: **TABLE B3**

Borehole Registration Number	Bore coordinates		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(lLs)	(mg/L)	
111768	318432	7361019	17.5	mudstone	WANDILLA FORMATION	2	13	-1	0.95	6532.5	ND
122116	321128	7356933	13	(Broken) mudstone	WANDILLA FORMATION	9	12	-5.5	0.88	4221	ND
111790	323710	7358662	16	mudstone	WANDILLA FORMATION	12.5	16	ND	0.56	2010	ND
88323	318973	7351885	16.2	(Decomposed & broken) slate	WANDILLA FORMATION	8.8	14	-8.1	0.5	2345	7.5
111763	324104	7358895	13.5	shale	WANDILLA FORMATION	8	13.5	-5.4	0.38	2077	ND
122115	322101	7353745	15	(Broken) mudstone	WANDILLA FORMATION	11	13	-7	0.38	1742	ND
136415	307015	7358134	24	mudstone	ROCKHAMPTON GROUP	13.7	14.6	-9	0.25	1809	ND
88327	318634	7357157	15.5	(Decomposed) slate	WANDILLA FORMATION	12.8	13.7	-7.62	0.19	2077	7.1
88304	317536	7355204	22.5	chert	WANDILLA FORMATION	20	ND	-4.9	0.06	3484	8.3
97147	293521	7355892	21	limestone		3	21	5.8	ND	1661.6	6.9
97175	292217	7356664	60	tuff		52	57	15.1	0.1	2465.6	8
111019	300940	7355463	24.4	diorite	MOUNT HOLLY BEDS	22.3		1.5	0.63	1675	ND
136212	317783	7355602	22.5	Sedimentary rocks	WANDILLA FORMATION	4	19	-9	0.25	1943	ND
136577	308150	7354588	24.38	andesite	ROCKHAMPTON GROUP	11.58	15.24	-4.57	0.25	3149	ND
136832	313468	7354159	27.7	mudstone	DOONSIDE FORMATION	19	20	-14	0.2	1943	ND
122817	316055	7353149	30.5	(Fractured) chert	DOONSIDE FORMATION	25	30.5	-17	0.38	1742	ND
122834	316055	7353146	30.5	(Fractured) sedimentary rocks	DOONSIDE FORMATION	18	30.5	-17	0.38	1742	ND
136398	309480	7359828	17	Fractured rock	BERSERKER BEDS	14	15.2	-9.1	0.63	1675	ND
136233	318003	7358050	52	Sedimentary rocks	WANDILLA FORMATION	49	52	-18	0.88	3149	ND

drawn	**KOS**
approved	
date	**29/04/2010**
scale	-
original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell LNG EIS GW Study**

title: Registered bores compiled from the DNRW Ground water Database showing a yield of <5L/s and a salinity of 1500 - 5000mg/L

project no: NSYSBRIS07033BB

Table no: **TABLE B3**

Borehole Registration Number	Bore coordinates		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(L/s)	(mg/L)	
122099	318565	7358255	28	chert	WANDILLA FORMATION	21	26	-9	1.01	2278	ND
136397	308956	7359919	12	Decomposed rocks	BERSERKER BEDS	7.6	9.1	-3	1.39	1742	ND
111919	299597	7374647	19	(broken) mudstone	BERSERKER BEDS	13	18	ND	1.64	3350	ND
91796	311068	7355572	24	(broken) mudstone	CRANA BEDS	15	24	-12	6.5	3417	ND
136396	309296	7360722	18	Fractured rocks	BERSERKER BEDS	13.4	14.6	-9.1	1.89	2211	ND
151038	323772	7355212	27.8	mudstone	WANDILLA FORMATION	24	ND	-10.8	4.42	3484	ND
111862	309204	7361442	19	RHYO	DOONSIDE FORMATION	12	19	-8	3.8	3685	ND
136819	312533	7354301	17.9	(broken) mudstone	CALLIOPE BEDS	15	18	-9	2.02	1742	ND
88339	309234	7361213	12.2	mudstone	BERSERKER BEDS	12.2	ND	-3	2.5	3705	ND
122984	294386	7361254	19.5	Fractured sedimentary rocks	MOUNT ALMA FORMATION	12	19.5	-3	1.5	4770	ND
97036	309627	7361276	22.2	Fractured&fresh andesite	DOONSIDE FORMATION	16	21.2	-11	6.5	1760.09	7.8
111792	317473	7356005	33	mudstone	WANDILLA FORMATION	31	33	-20	6.3	2010	ND
111151	309073	7361538	25	(broken) shale	BERSERKER BEDS	7.4	20	-7.4	5.5	2747	8.1
97177	293542	7356312	31	LMST		26.5	26.6	2	5	3082	

Note; Light yellow refers to a yield of <5L/s
Dark yellow refers to a yield between 5L/s and 15L/s

drawn	**KOS**
approved	
date	**29/04/2010**
scale	**-**
original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell LNG EIS GW Study**

title: Registered bores compiled from the DNRW Ground water Database showing a yield of <5L/s and a salinity of 1500 - 5000mg/L

project no: NSYSBRIS07033BB

Table no: **TABLE B3**

Borehole RN	Bore coordinates		Total Depth	Lithology	Formation	Aquifer Top	Aquifer Bottom	Static Water Level (SWL)	Bore Yield	Salinity	pH
	Easting	Northing	(m)			(mbgl)	(mbgl)	(mbgl)	(L/s)	(mg/L)	
111849	305251	7370650	3.96	Sand (decomposed granite)	TARGINIE GRANITE	3.35	3.96	-0.61	0.01	8375	6.5
122110	316707	7355278	11	Broken mudstone	DOONSIDE FORMATION	9	11	-8	0.19	6700	ND
91325	318603	7368993	27.3	mudstone	WANDILLA FORMATION	22.22	27.27	-10.6	3	8040	ND
122983	294473	7361101	19.5	Fractured sedimentary rock	MOUNT ALMA FORMATION	13	19.5	-5	0.76	7604.5	ND
111787	324072	7361518	ND	mudstone	WANDILLA FORMATION	36	37	ND	0.63	18090	ND
97176	294072	7361252	50	limestone		4	50	-3.7	ND	15946	ND
97585	293179	7359106	ND	ND	ND	ND	ND	-3.37	ND	6365	ND

Notes:
Data from Department of the Environment and Resource Management (DERM) registered bore database (accessed 2010)
ND: no data/record
mbgl: metres below ground level

drawn	**KOS**
approved	
date	**29/04/2010**
scale	**-**
original size	**A4**

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

client: **Shell Australia Liquefied Natural Gas (SALNG)**

project: **Shell Australia Liquefied Natural Gas EIS Groundwater Desk Study**

title: Registered bores compiled from the DNRW Groundwater Database showing a yield of <5L/s and a salinity of >5000mg/L

project no: NSYSBRIS0703BB

Table no: **B4**

Appendix C

Terms of Reference Cross Reference Table for the Groundwater Study

Table C1: Terms of Reference Cross Reference Table for the Groundwater Study

Term of Reference		Coffey Geotechnics	
Section	**EIS requirement**	**Technical Study Name**	**Technical specialist report section**
Section 3.4.2.1 Description of Environmental Values	The EIS should review the quality, quantity and significance of artesian and non-artesian groundwater resources within the project area.	Groundwater Study	Section 4.4 Groundwater resources Section 4.5 Hydrogeology
	The environmental values of the underground waters of the affected area should be described in terms of:		
	• values identified in the EPP (Water) Policy	Groundwater Study	Section 2 Legislative context and standards Section 5 Environmental Values
	• sustainability, including both quality and quantity	Groundwater Study	Section 4.4 Groundwater resources Section 4.5 Hydrogeology
	• physical integrity, fluvial processes and morphology of groundwater resources.	Groundwater Study	Section 4.5 Hydrogeology
	This section should include reference to:		
	Nature of the aquifer(s)	Groundwater Study	Section 4.5 Hydrogeology
	• geology/stratigraphy—such as alluvium, volcanic, metamorphic.	Groundwater Study	Section 4.3 Geology; Section 4.5 Hydrogeology
	• aquifer type—such as confined, unconfined	Groundwater Study	Section 4.5 Hydrogeology
	• depth to and thickness of the aquifers	Groundwater Study	Section 4.4 Groundwater resources Section 4.5 Hydrogeology Appendix B
	This section should include reference to: Hydrology of the aquifer(s):		
	• depth to water level and seasonal changes in levels	Groundwater Study	Section 4.4 Groundwater resources Section 4.5 Hydrogeology Appendix B
	• groundwater flow directions (defined from water level contours)	Groundwater Study	Section 4.5.4 Hydrogeology
	• interaction with surface water	Groundwater Study	Section 4.5 Hydrogeology Section 4.6 Groundwater Dependent Ecosystems
	• interaction with sea/salt water	Groundwater Study	Section 4.5 Hydrogeology Section 4.6 Groundwater Dependent Ecosystems

Term of Reference		Coffey Geotechnics	
Section	EIS requirement	Technical Study Name	Technical specialist report section
	• possible sources of recharge	Groundwater Study	Section 4.5.2 Groundwater Recharge and Discharge
	• vulnerability to pollution	Groundwater Study	Section 4.5.6 Groundwater Vulnerability
	The data obtained from the groundwater survey should be sufficient to enable specification of:		
	• the major ionic species present in the groundwater, pH, electrical conductivity, total dissolved solids	Groundwater Study	Section 4.4 Groundwater resources Section 4.5 Hydrogeology
	• The review should include a survey of existing groundwater supply facilities (bores, wells, or excavations).	Groundwater Study	Section 4.4.1 Registered Groundwater Bores
	The information to be gathered for analysis should include:		
	• location and type of facilities	Groundwater Study	Section 4.4 Groundwater resources Section 4.5 Hydrogeology
	• pumping parameters	Groundwater Study	Section 4.4 Groundwater resources Section 4.5 Hydrogeology
	• draw down	Groundwater Study	Section 4.5 Hydrogeology
	• recharge at normal pumping rates	Groundwater Study	Section 4.5 Hydrogeology
	• seasonal variations (if records exist) of groundwater levels.	Groundwater Study	Section 4.5 Hydrogeology
	• A network of observation points which would satisfactorily monitor groundwater resources both before and after commencement of operations should be developed.	Groundwater Study	Section 8 Inspection and Monitoring
	• The EIS should include an assessment of the potential environmental impact caused by the project (and its associated project components) to local groundwater resources, including the potential for groundwater induced salinity.	Groundwater Study	Section 6 Impacts
	• The impact assessment should define the extent of the area within which groundwater resources are likely to be affected by the proposed operations and the significance of the project to groundwater depletion or	Groundwater Study	Section 6 Impacts

Term of Reference		Coffey Geotechnics	
Section	**EIS requirement**	**Technical Study Name**	**Technical specialist report section**
	recharge, and propose management options available to monitor and mitigate these effects.		
	• The response of the groundwater resource to the progression and finally cessation of the project should be described.	Groundwater Study	Section 7 Significance Assessment and Mitigation; Section 8 Inspection and Monitoring
	• Any potential for the project to impact on groundwater dependent ecosystems should be assessed and described. Avoidance and mitigation measures should be described.	Groundwater Study	Section 6 Impact Section 7 Significance Assessment and Mitigation
	• An assessment of the potential to contaminate groundwater resources and measures to prevent, mitigate and remediate such contamination should be discussed.	Groundwater Study	Section 6 Impact Section 7 Significance Assessment and Mitigation